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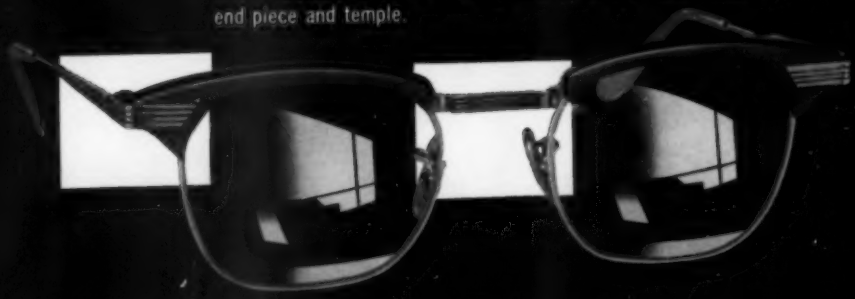

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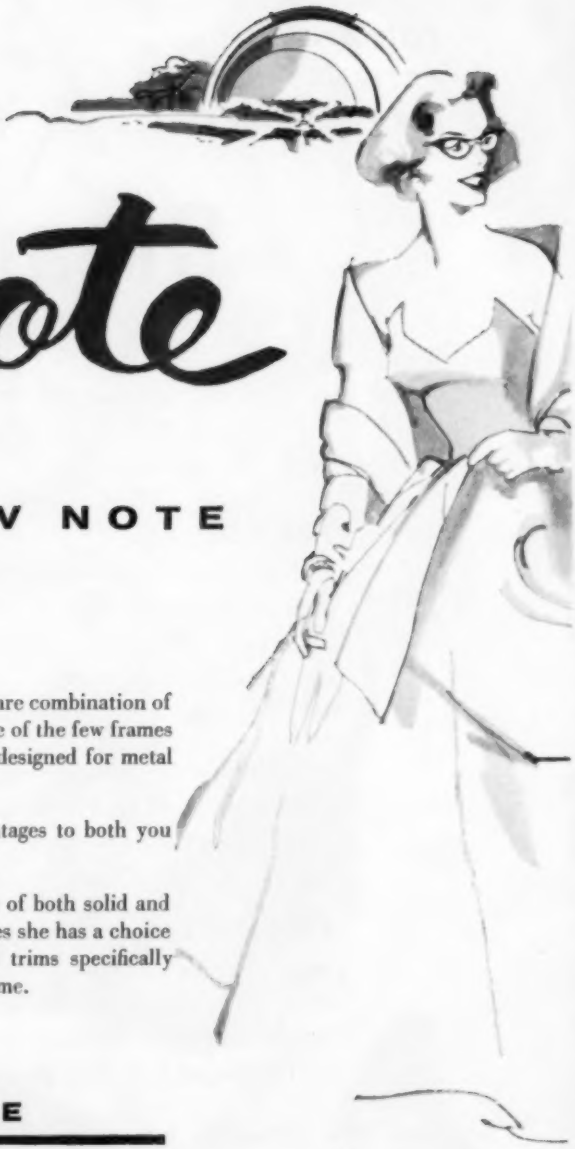

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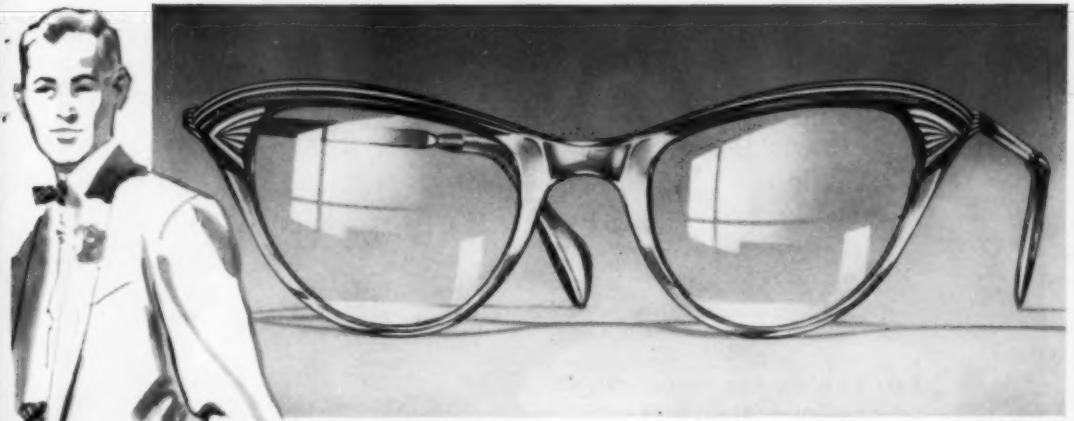

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AMERICAN JOURNAL OF OPTOMETRY
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THE RESTING STATE OF ACCOMMODATION*

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It is generally assumed that the condition of physiological rest of accommodation is established when an emmetropic eye, either natural or corrected, focuses accurately a distant target demanding good resolution. The fact that the optical value for the location of this target can be stated as being zero diopters from the eye has tended to make this idea even more acceptable than it might otherwise be: for what can represent less activity than zero? Many clinicians dealing with refractive errors tend to accept this thesis without question since lens corrections for ametropia apparently based on this particular definition of physiological rest seem satisfactorily to most of their patients.

A critical examination of this usual definition of the resting state of accommodation induces considerable doubt as to its validity. First, it contains a play on words since it involves the ideas associated with emmetropia, which has been defined as, "The normal condition of the refractive system of the eye, where rays from a distant object are focused sharply on the retina when the ciliary muscle is relaxed."[1] Second, it involves a fundamental error of physiology. Accommodation is usually considered the motor response to efferent impulses in a reflex situation. The afferent impulses are assumed to arise either because of retinal or cortical activity. In any event the normal stimulus is visual in nature. Usually the resting state of a reflex arc is determined when the afferent activity is zero. It is certain that this condition cannot exist when the eye is fixing an object and the brain is "seeing." In order to reduce these afferent impulses to zero, all visual stimuli must be removed from the situation. This could occur in two conditions—in complete darkness and in a luminous but completely empty visual field.

It is well known that in darkness the eye becomes myopic—so-called nocturnal myopia exists. In passing, it should be pointed out that this myopia exists relative to the refractive state determined clinically by the usual methods. While it is true that there is considerable

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debate as to the exact cause of nocturnal myopia,[2, 3, 4, 5, 6, 7, 8, 9] most of the evidence seems to indicate that a portion of the myopia present in scotopia is due to the increase in curvature of the crystalline lens, i.e., accommodation. The exact amount of this accommodative myopia is difficult to assess since the only really objective measurements of it have been made by Otero[4] who claims it to be about 1.25 D., by Campbell and Primrose[8] who claims it to be about 0.82 D., and Kooman, Scolnik and Tousey[7] who deny its existence. In other reports mentioning magnitudes, the major premise of the absence of a stimulus has been violated, usually doubly violated since the measuring lens which represents the myopia found may also act as a stimulus to accommodation. The alteration in the refraction is measured by a lens through which the eye views some target. As this lens is changed, there is an obvious alteration in the stimulus pattern. If the accommodation in night myopia, for example, is brought about to make the eye aplanatic as suggested by Ivanoff,[4, 5] then a concave lens placed before the eye will tend to vitiate this adjustment. The aplanatic condition of the eye plus lens can be restored under this circumstance only by an alteration in the accommodative mechanism. The best guess would appear to favor an amount of accommodative myopia of between 0.75 D. and 1.0 D. Thus the resting state of accommodation with regard to clinical emmetropia is apparently not zero but as has been pointed out by Campbell and Primrose,* "We prefer to think that what we have found is the resting position of the focusing mechanism. If one considers this mechanism as a reflex arc, when the afferent stimulus is removed as in darkness the efferent side should be in a state of repose."

In recent years it has been found that when the eye looks into an empty luminous field, it becomes myopic—space or sky myopia. In contrast to nocturnal myopia, there seems little doubt that a major portion of this myopia is due to accommodation.[10, 11, 12, 13, 14, 15, 16] Here again the amount of the myopia cannot be stated with certainty since the premise of no stimulus to accommodation was usually violated in the measurement of the accommodation. Nadell and Knoll,[14] Whiteside[15] and Heath,[16] who attempted to keep the stimulus effect of the measuring device to a minimum, found values closely approximating 1.00 D.

Luckiesh and Moss[17, 18] and Reese[19] determined the refractive error by finding that lens which, placed before the eye, would give the lowest contrast threshold. On the average, this was found to be about —0.75 D. over and above that lens which made the eye clinically emmetropic.

*Campbell & Primrose, *loc. cit.* p. 359.

Reese found that this difference between the sensotometric and the usual clinical refraction disappeared when the accommodative mechanism was paralyzed by homatropine.

Heath[16] has advanced the hypothesis that there are four stimulus factors in accommodation: (1) tonus; (2) convergence; (3) nearness; and (4) blurredness of the perceived image. In scotopia and photopia with an empty visual field, tonic accommodation becomes manifest. If a distant target with resolvable detail is viewed, tonic accommodation is inhibited to the extent necessary to resolve the detail. Thus tonic accommodation is inhibited in order to secure a sharp image of a distant object. The work of Nadell and Knoll[14] tends to confirm this to some degree since they found the measurable refractive error to vary slightly with the type of fixation target and the amount of detail.

Tait[20] has proposed a similar set of components for accommodation, namely, tonic, retinal, convergent and proximal. Tonic accommodation of Tait, however, is different than that of Heath. For Tait it is the difference between the cycloplegic refraction and the non-cycloplegic refraction and thus may be said to represent a "latent hypermetropia" whereas the tonic accommodation of Heath represents a "latent myopia."

It would thus appear that the state of physiologic rest of accommodation is not zero but is equivalent to approximately 0.75 D. to 1.00 D. of myopia. It must be remembered, however, that this accommodation is measured with respect to clinical emmetropia. This very factor tends to create doubt concerning this idea since clinical emmetropia is usually said to be established by that *maximum* convex lens or *minimum* concave lens which results in maximum acuity for a six meter viewing distance. There are some clinicians who substitute "standard acuity" for "maximum acuity." As a consequence of this working definition, there is always a plus bias in the establishment of clinical or artificial emmetropia. The amount of this bias varies not only with the subject but also with the clinician (some clinicians have a reputation among their colleagues for "crowding the plus"). The amount of this extra convex power could be equal to at least half the depth of focus of the eye.

Von Bahr[21] found the depth of focus by direct measurement to be between 1.00 D. and 1.50 D., and thus half would be 0.50 D. to 0.75 D. Campbell[22] reported that the depth of focus of the eye with a 3 mm. pupil is ± 0.50 D. to ± 0.60 D. Hofstetter[23] and Morgan[24] have reported similar values for one-half the depth of focus. The depth of focus of the eye and the plus bias of refraction may well mean that clinical emmetropia is essentially the condition in which for some

easily maintained and duplicated state of accommodation* the point conjugate to the retina is between 0.50 and 0.75 D. of myopia on the average.

This might mean that some portion of nocturnal myopia and sky myopia is due merely to a shift in the frame of reference and does not involve an actual change in the accommodative state. It is well known that the magnitude of nocturnal myopia is reduced when a cycloplegic is used. The difference between sensotometric and routine refraction result is also minimized by cycloplegia. In some cases the amount of nocturnal myopia has been determined by photographing the Purkinje-Sanson images. This method detects not a change in the overall refraction of the eye but a change in the curvature of the crystalline lens, i.e., accommodation. All this might be taken as proof that the plus bias of routine refraction does not affect the conclusion that accommodation becomes activated when the afferent stimulus is reduced. There is, however, some indirect and inferential evidence which cannot be overlooked.

Among others, Hofstetter[22] has determined carefully the zone of single clear binocular vision. It has been found that when convergence is inhibited by means of base-in prisms, accommodative-convergence and hence accommodation is likewise inhibited near the limits of divergence. It would be logical to assume that one had reached the "zero level" of accommodation when it was no longer possible to elicit this inhibition of accommodative-convergence. Generally speaking, this appears to be the case when the fixation distance is equivalent to 0.50 to 0.75 D.

Flom[25] has measured the response of the accommodative-convergence mechanism to added lens power for distance fixation. It is thought that accommodation cannot be changed without changing accommodative-convergence.[26] Flom found that it was necessary, on the average, to add —0.50 D. before any change in convergence could be noted. All of his subjects were made artificially emmetropic, however; a definite attempt was made to avoid the plus bias generally present. Consequently it is a fair inference to believe that subjects routinely refracted would show no response to lens changes as great as —0.75 D.

This evidence is further enhanced by the investigations of Marg[27] and Knoll,[28] who found that the pupillary near reflex was associated with accommodation (Marg) or accommodative-convergence (Knoll)

*Easily maintained and duplicated since two or more clinicians determining the refractive state of the same eye will find almost identical results.

rather than with fusional convergence. Adler[29] has pointed out that "the contraction of the pupil begins only the moment that the fixed object is at a distance of 0.5 meter and not at the moment accommodation begins." Unfortunately this observation is based on the assumption that accommodation changes exactly with the fixation distance. This objection, however, is overcome in the work of Marg, who measured the total refractive power of the eye using a coincidence optometer on a haploscope. He found that "pupillary diameter as a function of accommodation is linear, although in some cases only after about the first diopter."

This indirect evidence seems to lend strength to the assumption that the first 0.75 D. of accommodation is illusory rather than factual and lends strength to the plus-bias-depth-of-focus theory. The data are, however, subject to a different interpretation: namely, the first 0.75 D. of accommodation is mediated in some other fashion than the balance of the accommodation.

This interpretation would assume (1) that the resting state of accommodation is present when the eye is in focus for objects about one meter away; (2) that more distant objects are brought into focus by an active negative accommodation which does not influence either accommodative-convergence or pupil size; and (3) that nearer objects are brought into focus by active positive accommodation which does influence accommodative-convergence and pupil size. This theory would be greatly enhanced if one could demonstrate negative accommodation and could provide a mechanism for its action.

There have been some reports in the literature of measurements of negative accommodation. Otero[4] in discussing nocturnal myopia and nocturnal presbyopia quotes measurements made by Duan in which three subjects demonstrated negative accommodation in photopic vision to the extent of at least 1.00 D. LeGrand,[30] using skiametry, found five subjects who showed negative accommodation during "flashes of clear vision" while wearing too much convex lens power. On the other hand Marg[31] in an intensive investigation of subjects demonstrating such "flashes of clear vision," could find no change in the refractive state of the eye by either skiametry or coincidence optometry. Morgan and Olmsted,[32] using skiametry to measure the changes in refractive state, reported that sudden sensory stimuli, such as an electric shock or a loud noise, may cause a momentary decrease in the refractive power of the eye, usually not more than 0.25 D.

It has been established that stimulation of the cervical sympathetic and the long ciliary nerves in animals will cause an increase in hyper-

metropia.[33, 34, 35, 36] The mode of action of the sympathetic, whether it be vascular or muscular or both has not yet been fully established. It is intriguing to postulate that this action of the sympathetic might induce negative accommodation. There is some doubt, however, that such is the case. In the intact animal the time characteristics of the response seem too slow when the sympathetic is stimulated. More important, there is a recovery from the effects of sympathectomy with time. One cannot tell any difference in accommodative function between the affected and the unaffected eye in subjects with longstanding unilateral Horner's syndrome. This means that it is possible to state definitely that accommodation for distance vision is normal without sympathetic innervation.

Thus there is some evidence that negative accommodation does exist and there is also evidence as to a mechanism whereby accommodation can be altered independently of the oculomotor nerve. These factors tend to lend support to the theory that the normal resting state of accommodation could be equivalent to about 0.75 D. of clinical myopia. While it is true that the plus bias inherent in clinical emmetropia tends to create a certain amount of doubt as to the correctness of this idea, the balance of the evidence presented would seem to favor this idea concerning the physiologic state of rest of accommodation.

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EFFECT OF VARIATIONS IN COLOR OF PRINT AND BACKGROUND UPON EYE MOVEMENTS IN READING*

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The extensive use of color in magazine advertising, posters, car cards, booklets and circulars emphasizes the importance of scientific knowledge concerning the effect of various color combinations of print and background upon the legibility of printed text. This may be studied by means of performance tests or through analysis of oculomotor patterns. The latter may well supplement the former in the building of a scientific typography. In some ways, study of eye-movement patterns will provide more information than a performance test which measures only speed of reading. In addition to speed of reading (perception time), the eye-movement measures will reveal the basis for variation in the rate of reading. For instance, variation in legibility of the printing may produce changes in fixation frequency or regression frequency or pause duration or all three.

The purpose of the present study is to investigate the effect of various color combinations of print and paper background upon eye-movement patterns during reading. The eye-movement measures considered are fixation frequency, regression frequency, fixation pause duration, and perception time (fixation frequency times pause duration). Each subject read a selection for each color combination of ink and paper. The order of presentation was randomized by means of a Latin Square design. Analysis of the data will determine whether the averages of the various color combinations differ significantly.

MATERIALS AND PROCEDURE

Stimulus materials consisted of Form B of the Chapman-Cook Speed of Reading Test printed in seven combinations of colored ink and

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colored paper. Seven different sets of reading selections were made up. Each set consisted of one card for each of the seven color combinations. On each card were four paragraphs (of 30 words each, 120 words in all) from the Chapman-Cook test. Table I shows how the cards were made up.

TABLE I

Paragraphs of the Chapman-Cook Speed of Reading Test Assigned to the Various Color Combinations in the Different Sets of Stimulus Material.
Note: The numbers within the table are the paragraph numbers in the Chapman-Cook Test.

Color Combination	Set Number						
	I	II	III	IV	V	VI	VII
Grass Green on Tulip Red	1-4	5-8	9-12	13-17	18-21	22-25	26-29
Chromium Orange on White	5-8	9-12	13-17	18-21	22-25	26-29	1-4
Tulip Red on White	9-12	13-17	18-21	22-25	26-29	1-4	5-8
Black Jobbing on Yellow	13-17	18-21	22-25	26-29	1-4	5-8	9-12
Black Jobbing on White	18-21	22-25	26-29	1-4	5-8	9-12	13-17
Tulip Red on Green	22-25	26-29	1-4	5-8	9-12	13-17	18-21
Black Jobbing on Purple	26-29	1-4	5-8	9-12	13-17	18-21	22-25

The reading materials of the different color combinations, as shown in Table I, were set up in a 7x7 Latin Square design so that a reading selection (four paragraphs on a stimulus card) occurred only once in any column, and in any row. There were seven Latin Squares in all. They were the same except that different reading selections (paragraphs) were used for the color combinations.

The 49 college students who served as subjects were divided into groups of seven. Each block (group) of seven subjects read the materials in the color combination for one *set* of the stimulus cards as shown in Table I. When all the data were pooled, material in each color combination had been read 49 times (once by each subject) with each reading selection read seven times, i.e., 7 subjects in each of the 7 Latin Squares = 49. Thus every color combination was used an equal number of times for each set of paragraphs, but the order of presentation of the material was randomized by use of a Latin Square. By this arrangement, every subject read all the color combinations.

Photographic records were obtained during the reading by means of the Minnesota eye-movement camera.[3] Each subject read a practice exercise before the camera prior to the experimental series. The records were read and the data tabulated to obtain the following eye-movement measures: fixation frequency, pause duration, perception time (i.e., fixation frequency times pause duration), and regression frequency. Means for each of the 7 sets of paragraphs and for the 7 color combinations were computed. The analysis of variance technique was employed to evaluate the significance of the results.

RESULTS AND DISCUSSION

To economize on space, the detailed tables of means within cells of the Latin Square and analysis of variance will not be presented here. However, a summary table will be given below.

PERCEPTION TIME

On the average, perception time (total time devoted to pauses) takes up about 94 per cent and eye movements 6 per cent of the reading time. Since there is no clear vision during the eye movements, perception occurs during the pases (see Tinker[4]).

The over-all means for perception time suggest that the more legible color combinations are materials printed in black on yellow, red on white, green on red and black on white; the less legible are red on green, orange on white and black on purple.

The analysis of variance revealed that the differences between color combinations is highly significant, beyond the 1 per cent level. The differences between selections (particular paragraphs read) is also highly significant but the interaction between color combinations and selections is not significant.

FIXATION FREQUENCY

The means for fixation frequency show that the more legible color combinations are black on yellow, red on white, green on red and black on white; the less legible, red on green, orange on white and black on purple.

Again the analysis of variance showed high significance between color combinations and between selections but lack of significance for interaction between the two.

PAUSE DURATION

Means for pause duration suggest that the more legible color combinations are black on white, green on red, red on white and black on yellow; the less legible, red on green, orange on white, and black on purple.

The analysis of variance showed high significance between color combinations but lack of significance between selections and for interaction between the two.

REGRESSION FREQUENCY

The mean scores for regression frequency suggest that the more legible color combinations are red on white, black on yellow, green on red and black on white; the less legible, red on green, orange on white and black on purple. However, the analysis of variance revealed no significant difference for any of the comparisons.

A summary of the data of the study is given in Table II. Mean

TABLE II

Overall Means for Eye-Movement Measures and Legibility Ranks of Color Combinations

Color Combinations	MEASURES* Perception Time		Fixation Frequency		Duration of Pauses		Regression Frequency		Ranks Combined	
	Mean	Rank	Mean	Rank	Mean	Rank	Mean	Rank	Mean	Rank
Black-White	17.9	4	78.8	4	6.7	1	11.8	4	3.25	4
Green-Red	17.6	3	77.2	3	6.8	3	11.5	3	3.00	3
Red-Green	24.5	7	91.7	7	8.0	7	13.8	7	7.00	7
Orange-White	22.8	6	89.7	6	7.6	6	13.7	6	6.00	6
Black-Purple	20.2	5	83.8	5	7.2	5	12.7	5	5.00	5
Red-White	17.5	2	77.0	2	6.8	3	10.6	1	2.00	2
Black-Yellow	17.4	1	75.8	1	6.8	3	10.8	2	1.75	1

*Under these measures are the means for reading four paragraphs (120 words) of the Chapman-Cook Speed of Reading Test printed in the indicated color combinations of ink and paper by 49 subjects. The mean scores are in seconds for perception time, number of fixations for fixation frequency, 1/30 second for duration of fixation pauses, and number of regressions for regression frequency.

scores for the various eye-movement measures for reading each of the combinations of colored ink on colored paper are given. The color combinations are also ranked for legibility. Best legibility is indicated by smallest mean score for each measure.

Examination of the rankings for legibility reveals a striking agreement from measure to measure. The combined rankings are given at the right of the table. In terms of legibility, the color combinations of printed material appear to fall into two groups:

(1) Best legibility: black on yellow; red on white; green on red; black on white.

(2) Worst legibility: black on purple, orange on white; red on green.

Perhaps a better understanding of the results may be obtained by noting how the ink and paper looks to the observer. The test material was printed with Ruxton's colored ink on Rainbow cover stock. Below are given the color combinations and the observed effects. The first column gives the trade names of the ink and the cover stock and the second column states what the printing looked like.

Trade Name (1)	Observed Effect (2)
Black jobbing on white	Black on light grayish white
Grass green on red	Dark grayish green on red (dark tint)

Tulip red on green	Dark brown on dark green
Chromium orange on white	Light orange on light grayish white
Black jobbing on purple	Black on dark purple (violet)
Tulip red on white	Light red on light grayish white
Black jobbing on yellow	Black on yellow (slight orange tinge)

An examination of the observed effect reveals that there is relatively small contrast between ink and paper for the color combinations that produce worst legibility. There was either dark print on dark background (black on purple, red on green) or light print on light background (orange on white). The contrast between print and paper was good for the combinations of best legibility. Employing a speed of reading technique and the same color combinations as in this study, Tinker and Paterson[2] obtained results comparable to those in this investigation. With the same color combinations and still another technique (perceptibility of print at a distance), Preston, Schwankl and Tinker[1] also confirmed the results of the present study. The results of the present investigation plus supporting evidence leads to the conclusion that the greater the brightness contrast between printing ink and paper background, the greater the legibility of the printed material.

It is not surprising that the eye-movement technique produces clear-cut results. Tinker[5] demonstrated that eye-movement measures have high reliability when an adequate experimental design is employed. In the same study Tinker found that perception time and fixation frequency are valid measures of reading performance. Pause duration would also be a valid measure of reading performance in situations where visibility of printed symbols is involved as in the present study.

Eye-movement records provide useful information beyond mere reading speed. They reveal patterns of oculomotor behavior that indicate the reason for fast or slow reading. For instance, in reading black print on light yellow paper the perception time, fixation frequency, pause duration and regression frequency are relatively small while in reading red print on dark green paper, they are all relatively large. Tinker and Paterson[6] have presented a variety of oculomotor patterns that are related to typographical variations.

SUMMARY AND CONCLUSIONS

1. Analysis was made of oculomotor patterns employed during the reading of material printed in a variety of combinations of colored ink and colored paper.

2. The reading materials were organized in a Latin Square design for presentation to the readers.

3. The eye movements of 49 subjects were photographed while reading samples of four short paragraphs in each of the color combinations of ink and paper.

4. The analysis of variance technique was employed to evaluate the obtained data.

5. Each of the eye-movement measures (perception time, fixation frequency, pause duration and regression frequency) showed variation from one color combination to another in such a way as to indicate print of good legibility and of poor legibility.

6. The color combinations of printed material fell into two groups: (a) Black on yellow, red on white, green on red, and black on white provided best legibility. (b) Black on purple, orange on white, and red on green provided worst legibility. These results are in harmony with the findings of other investigations. Apparently the eye-movement technique is a valid procedure for studying the legibility of print.

7. The results of this study appear to emphasize the role of brightness contrast between printing ink and paper background in achieving best legibility of copy. If maximum legibility is to be obtained the following rule should be adhered to: In combining colors (print and background) care must be exercised to produce a printing arrangement with a maximum brightness contrast between print and background. This means that the printer should disregard color as such and should direct his attention to brightness contrast. Therefore, two shades (dark colors) or two tints (light colors) in print and background should be avoided. For best legibility, a dark color should be used for the print and a light color (tint) should be employed for the background. In general, the darker the ink and the lighter the background, the better the legibility.

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VISUAL PROJECTION IN WALKING EXPERIMENTS*

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INTRODUCTION

It is customary to describe the visual perception of space by saying that perceived images of objects are "projected" out into space from a "center of projection." This paper is the first of a number of reports which will be concerned with the analysis of projection patterns found in normal binocular subjects, one-eyed subjects, and in normal correspondence and anomalous correspondence squinters. It is hoped that a knowledge of the similarities and differences in the patterns of projection exhibited by the various types of subjects used will help our understanding of anomalous correspondence in squinters.

Crossed eyes, squint, and strabismus are synonymous terms denoting an inability to direct both eyes to a single object. Although this condition almost never causes any real pain and probably interferes little with the performance of most every day tasks, it has been the subject of investigation by workers in the field of vision for centuries.

Two reasons probably best explain this interest: first, an understanding of how a squinter sees is necessary for a complete understanding of binocular vision and secondly, this clearly visible defect imposes upon the possessor the stigma of inferiority. Hence, persons who have this defect want it corrected.

Methods of treating this condition have taken many forms principally because its real nature and its causes have been so poorly understood. In addition, the physical appearance of the eyes gives little or no clue to the visual or sensorial adaptations which may have accompanied the mechanical deviation of one eye relative to the other.

In everyday life, objects seen in the field of view of one eye are perceived in different directions with respect to ourselves. The apparent angular separation of these objects is related to the angular separation of the images of the objects on the retina, i.e., to each retinal element there is attached a specific directional value which is dependent

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on the point in the cortex where the impulse impinges. The fovea is the "principal visual direction." Lotze in 1852[1] labeled this the visual "local sign."

Normal binocular individuals who are able to direct both foveas to the same object must have retinal elements in one eye which will give rise to the same visual direction as will similarly placed elements in the opposite eye in order for a unitary concept of direction to take place. This fact Hering[2] referred to as the law of identical visual directions (Figure 1). This law implies that different objects whose

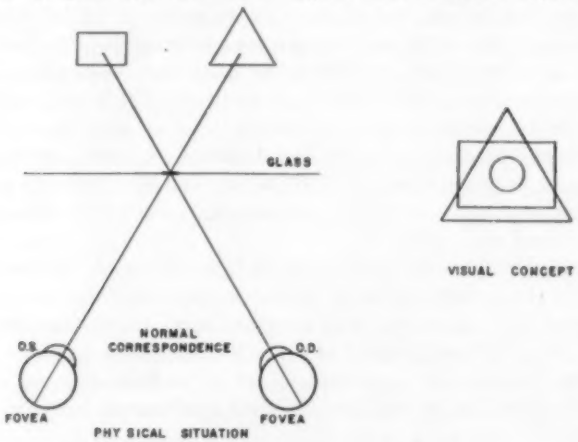

Fig. 1. Hering's Law of Identical Visual Directions. On the glass plate a circle is inscribed through which the right eye sees a square. The left eye sees a triangle through this same circle. The visual concept is that of a circle, square, and triangle all in the same direction.

images fall simultaneously upon the foveas or other corresponding areas of the two eyes will be seen in a single subjective direction even if they are actually separated in object space. Persons possessing this faculty of "common visual directions"[3] are said to have normal correspondence.

Among squinters there are also some who are capable of demonstrating common visual directions with the two foveas, e.g., with the after-image test (Bielschowsky). These we refer to as normal correspondence squinters.

The squinters who are of primary concern here, however, are those in whom it is usually possible to demonstrate the existence of the local sign attribute in each retina when one eye is used alone but in

whom the two retinas do not exhibit common visual directions when corresponding areas of the eyes are stimulated simultaneously. On the contrary, considerable evidence exists which seems to indicate that the fovea of one eye is functionally united to an off-foveal area of the opposite eye in so far as directional values are concerned. This latter type of squinter is said to possess anomalous correspondence.

Orientation of ourselves and of objects around us depends upon three mechanisms. First, kinesthesis, which in the case of the eyes probably depends mainly on an "innervational sense,"[4, 5, 6, 7, 8, 9] keeps us informed of the position of our eyes with respect to the head. The proprioceptive type of kinesthesis keeps us informed of the position of the head and limbs with respect to the body and its physical contacts and their orientation with respect to gravity and similarly acting forces. The vestibular system aids the kinesthetic sense in keeping us aware of changes in the position of the head and also of the position of the head with respect to gravity and similarly acting forces. These two systems provide us with clues as to the absolute or egocentric localization of objects around us.

Finally, the visual mechanism, which begins in the retina and extends to the occipital lobe of the brain, gives us information about the relative or oculocentric direction of objects. Hence, the kinesthetic system, the vestibular system, and the visual system combine to give information which can contribute to one's awareness that an object is located in space in a given position with reference to his head, limbs, and body.

Even though we speak of images of objects being "projected" out into space, it should be pointed out that the term "projection" is not used to imply that the observer is first aware of a point on the retina being stimulated and then uses this information to construct an image which he "projects" somewhere into the space surrounding him.[10] The observer is aware only of the object which exists in space in front of him; he is not conscious of having received coded bits of information which have to be re-interpreted as an impression of an object.

The term "lines of projection" is used in a geometric sense to designate the lines in visual space which are analogous to the lines of sight in physical space. The point at which these lines of projection converge is called the center of projection.

Editors note:— Several additional papers dealing with anomalous correspondence in squinters by Dr. Neal J. Bailey will appear during the coming year. The first of these will be published in one of the Fall issues.

Studies have been conducted mainly on normal binocular subjects,[2, 4, 11, 12, 13, 14] but also on squinters[3, 12, 15, 16] in an effort to identify this center (or centers) of projection with some anatomical reference point. In the case of remote objects, no problem is presented in assuming this "center" to be anywhere on the observer's body. In the case of near objects, however, and in the special problems associated with squint, there is a need for a more precise localization of the center from which perceived objects are projected.

Investigations of projection patterns and of the location of the center of projection are hampered by a number of problems. Though nearly all of us operate on the basis that objects are what they "look" like and are located where they "appear" to be located, it is true that the configuration and location of these objects may be quite different from what our subjective impressions would indicate. This paper will report one method which was used to study the problem of visual direction only. The results of this study were then used in experiments to be reported later to help determine the "center" from which these directions are "projected."

One of the assumptions upon which projection studies are based is that a normal binocular individual using one or both eyes sees a foveally fixated object in a direction parallel to the bisector of the angle of convergence. The correctness of this assumption was tested by two experiments. One of these experiments involved walking in the direction of a distant target. In the second experiment, the subject was permitted to see objects on top of a specially constructed table and was required to localize them with the hands which were kept hidden from view under the table. Only the walking experiments will be

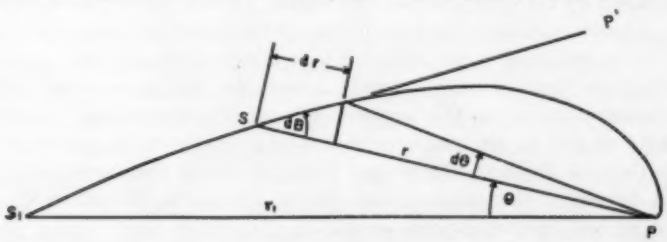

Fig. 2. Path Taken by a Subject Whose Projection Is Faulty. The path taken by a subject whose projection is in error probably can be described by a transendental curve or spiral for which r, the radius of the curve, changes continuously with changes in the vectorial angle, Θ. Mathematically, a change in the vectorial angle of 2π would result in a complete circuit of the point P. In practice, however, the subject usually approaches P without circling it. Hence, the terminal portion of the spiral does not encircle P. P' represents the projected direction of P.

described in this paper. The responses obtained with normal binocular subjects were then compared to those of one-eyed subjects, normal correspondence squinters, and anomalous correspondence squinters.

If a person who is looking at a distant target is asked to indicate the direction of this target from himself, he can walk toward it and his path can be used to indicate the perceived direction of the target. This path will be a straight line to the target if the target is localized correctly from the start; but if the subject's projection is in error, his path will form a spiral like that shown in Figure 2. The radius, r, of this transcendental curve will change continuously with the change (measured in radians) in the vectorial angle, θ, and the curve can be described by the equation[17]

$$\frac{d\,\theta}{dr} = \frac{\tan B}{r_1}$$

$$\theta = \ln \frac{r}{r^1} \tan B$$

As is evident in the drawing (Figure 2) and in the equations above, if r_1 is sufficiently large, the initial portion of the spiral will be indistinguishable from a straight line. The arrow points to P′, the projected direction of the distant target, P.

This experiment was set up in a large open outdoor field. The subject was placed in the starting position with the center of his back in contact with a vertical string suspending a plumb bob. He was then instructed to walk toward a target 1,000 yards away. After walking about 50 yards "toward the target," the subject's path direction was determined by the experimenter (see Figure 3).

The vertical string and plumb line were placed two meters in front of a horizontal two-meter stick. A line drawn from the distant target through the vertical string would bisect the two-meter stick. The experimenter stood on the opposite side of the meter stick from the plumb bob and by the visual extension of a line from the center of the subject's back through the plumb line and across the meter stick, he could determine the angular direction of the subject's path from the target in 1/20 prism diopter steps.

BINOCULAR SUBJECTS

In the case of binocular subjects, some trials were run with both eyes open. However, in the case of squinters who might use either eye for fixation or even change fixation during a trial, one eye was kept covered. The average path deviation, computed on the basis of five

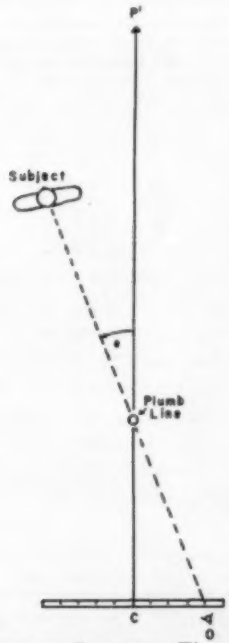

Fig. 3. Path Direction Measurement Apparatus. The subject starts from a position in which the center of his back is in contact with the plumb line. His path at the moment of measurement is represented by the dotted line from the center of his back through the plumb line across the horizontal two meter stick and to the experimenter's eye, O. The angle, e, represents the path deviation in prism diopters. A line from the point, C (the midpoint of the two-meter stick), through the plumb line points to the physical object, P.

trials, was used to evaluate the accuracy of each subject's projection. The data for three binocular subjects are shown in Table I.

It can be seen that the subjects walk quite straight toward the target using both eyes or one eye alone when no prisms are placed before the eyes. However, when prisms over one or both eyes were used to change the direction of fixation, it was found that the path of the subject deviated less than would be predicted on the basis of the power of the prism. This lack of agreement between the predicted direction and the actual direction taken by the subject was suspected to be due to his ability to see the ground and objects around him as he walked.

In order to prevent the subject from using any clues to direction except the target itself, special goggles with a two mm. opening placed two cm. in front of each eye were devised from a pair of conventional

TABLE I. "Walking experiment" data for three normal binocular subjects. No peephole goggles were used. Deviations to the right are indicated by a plus sign (+); to the left, by a minus sign (—). All measurements are in prism diopters.

Eye	Prism	Base	Average Deviation	Expected Deviation	Difference
Subject: G. F.					
O.U.	0	—	+0.8	—	—
O.U.	18	L	+20.1	+18.8	1.3
O.U.	18	R	—12.3	—17.2	4.9
Subject: F. B.					
R	0	—	+0.6	—	—
R	10	R	—2.0	—9.4	7.4
R	10	L	+8.6	+10.6	2.0
R	18	R	—9.8	—17.4	7.6
R	18	L	+16.4	+18.6	2.2
L	0	—	+0.6	—	—
L	10	R	—6.2	—9.4	3.2
L	10	L	+3.6	+10.6	7.0
L	18	R	—11.6	—17.4	5.8
L	18	L	+14.0	+18.6	4.6
Subject: J. H.					
O.U.	0	—	+1.3	—	—
O.U.	18	R	—10.9	—16.7	5.8
O.U.	18	L	+10.6	+19.3	8.7
R	0	—	+1.4	—	—
R	18	R	—13.9	—16.6	2.7
R	18	L	+12.8	+19.4	6.6
L	0	—	—1.0	—	—
L	18	R	—13.6	—19.0	5.4
L	18	L	+13.9	+17.0	3.1

safety goggles with side shields. The subject wore these over his customary spectacles if spectacles were worn.

Table II shows data for N.B. taken without the special goggles, and Table III, with the special goggles. Without the goggles, path deviations are less then the expected but when the special goggles are worn the deviations are almost exactly as predicted by the power of the prism used.

TABLE II. "Walking experiment" data for subject N.B., a normal binocular subject. *No peephole goggles were used.* Deviations to the right are indicated by a plus sign (+); to the left, by a minus sign (—). Measurements are in prism diopters.

Eye	Prism	Base	Average Deviation	Expected Deviation	Difference
O.U.	0	—	—0.2	—	—
R	0	—	0	—	—
R	10	R	—5.6	—10.0	4.4
R	10	L	+5.0	+10.0	5.0
R	18	R	—14.6	—18.0	3.4
R	18	L	+14.6	+18.0	3.4
L	0	—	—0.6	—	—
L	10	R	—6.6	—10.6	4.0
L	10	L	+4.2	+9.4	5.2
L	18	R	—14.8	—18.6	3.8
L	18	L	+10.8	+17.4	6.6

Table III. "Walking Experiment" data for subject N.B., showing the more precise agreement between prism power and the subject's path deviation when the special goggles were used. Deviations to the right are indicated by a plus sign (+); to the left, by a minus (—) sign. Measurements are in prism diopters.

Eye	Prism	Base	Average Deviation	Expected Deviation	Difference
R	0	—	+1.8	—	—
R	18	R	—15.3	—16.2	0.9
R	18	L	+19.1	+19.8	0.7
L	0	—	+3.1	—	—
L	18	R	—16.0	—14.9	1.1
L	18	L	+21.2	+21.1	0.1

Monocular data for five binocular subjects wearing the goggles but without auxiliary prisms are presented in Table IV. The total path deviation predicted for either eye on the basis of the phoria is shown in parenthesis to the right of each average path deviation. Errors in projection as indicated by this experiment are small enough so that it may be concluded that projection in binocular subjects is parallel to the bisector of the angle of convergence. In the case of subject D.S., marked suppression of the left eye was apparent during parts of the testing procedure. This problem will be discussed further in connection with a later phase of this study.

Table IV. "Walking experiment" data for five normal binocular subjects showing the path deviation when one eye was covered and the special goggles worn. Phoria and path deviations are measured in prism diopters. A plus sign (+) indicates a deviation to the right; a minus sign (—), to the left. Deviation predicted on basis of phoria is shown in parenthesis to right of each deviation.

Subject	Phoria	Deviation Right Eye	Deviation Left Eye
F. B.	ortho	+0.6 (0)	+0.6 (0)
J. E.	6 exo	—0.5 (—3.0)	+2.1 (+3.0)
H. G.	5 eso	+0.8 (+2.5)	—0.9 (—2.5)
J. H.	4 exo	+1.4 (+2.0)	—1.0 (—2.0)
D. S.	1 exo	—1.1 (+0.5)	—4.6 (—0.5)

The predicted direction of projection as a result of the phoria is based upon the assumption that when innervation is supplied to the eye muscles, it is supplied in equal quantity to each eye (Hering's Law of Equal Innervation). If an esophoria is present, the eyes are assumed to make a convergence movement which, by itself, causes both lines of sight to intersect at the midline closer to the subject than the distant target which is also on the midline. Each eye would overconverge an amount equal to one-half the phoria. If neither eye were covered, innervation of equal amount to each eye would be furnished which would cause each eye to execute a divergent fusional movement equal to one-half the phoria and the target would be seen singly and still on the midline.

If, however, one eye, e.g., the left, were covered, as in this experiment, and the eyes had over-converged so that the right eye was looking to the left of the distant target, a fixational movement would be substituted for the fusional movement. Sufficient innervation to turn the right eye to the right through an angle equal to one-half the phoria would be furnished to the right eye and the left eye so that a conjunctive or yoked movement to the right would occur. Since fixational movements are interpreted by the subject to imply that the object has moved laterally a distance equal to the mean change in direction of gaze of the eyes, the target would now be seen to the right of its actual position by an angular amount equal to one-half the phoria.

SQUINTERS

In order to determine the type and amount of strabismus existing in each subject used for this part of the study, at least two tests were used. In all cases, as with the normal subjects, their customary spectacle correction (if any) was used throughout all testing.

Since an experiment to be described later demanded a knowledge of the accommodative convergence relationship, the objective angle of squint with relaxed accommodation and with various amounts of accommodation in play was measured on the Wottring Troposcope if visual acuity in each eye was 20/40 or better. In the case of amblyopes with less than 20/40 in either eye, this same information was obtained using the "table troposcope" described below. From the data collected, the objective ACA was computed for each subject.

The measurement of the angle of squint in amblyopic subjects presents a problem since fixation of the amblyopic eye is frequently off-foveal. It is, therefore, usually necessary to make use of a corneal reflex method of measurement.

A type of synoptophore or troposcope was devised which allowed for measurement of the change in squint angle to about one-tenth of one degree accuracy. An eight inch Circline fluorescent tube, C, served as a corneal reflex light source (Figure 4).

The subject's head was held in position by means of a chin and forehead rest placed along one edge of the table. In front of the amblyopic eye, R, was a back surface mirror, M, by means of which the light from the fluorescent tube, C, was reflected onto the eye. The light reflected from the cornea traveled back along this same path and the corneal reflex was observed through the telescope, F, placed one meter from the subject on the side of the amblyopic eye and at the center of the circle formed by the Circline tube. If a vertical deviation of the eye was noted, the height of the Circline tube and telescope was changed

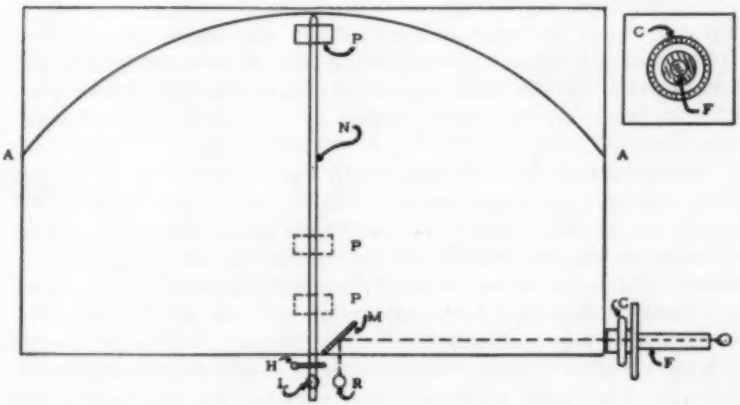

Fig. 4. The Table Troposcope. The amblyopic subject's head is fixed in position by means of a forehead and chin rest. His "good" eye, L, which is in vertical alignment with the rotation axis of the rod, N, maintains clear fixation on the smallest readable letters of a photographically reduced Snellen Chart, P. The rectangles, P, represent positions of this Snellen Chart varying from one meter to 20 cm. from the spectacle plane of the fixating eye. A lens holder, H, is used to hold a +1.00 diopter sphere which optically moves the target from one meter to infinity. The arc, AA', is a scale calibrated in degrees and along which a pointer on the rod, N, moves.

In front of the amblyopic eye, R, is a mirror, M, by means of which the corneal reflex source produced by an eight-inch Circline fluorescent tube, C, is reflected into the eye. The light reflected from the cornea of R travels back along this same path and is observed through the telescope, F, which is centered in the Circline tube (see cut at upper right of main drawing).

so that the corneal reflex was centered. No measurement of the vertical deviation was made.

The fixation target, P, was a photographically reduced Snellen chart. It was mounted on a rod, N, which rotated about an axis placed in vertical alignment with the center of rotation of the fixating ("good") eye, L. This target was placed at distances from one meter to 20 cm. from the eye and, by placing a plus one diopter sphere in the lens holder, H, a stimulus to accommodation was produced which varied between zero and five diopters. Rotation of the target through an angle of 40 degrees on each side of the straight foreward position was possible. A scale, AA', mounted on the table top, calibrated in one degree steps on a one meter arc, allowed easy estimation of the angle of turn to about one-tenth of a degree.

Clear fixation on the smallest letters possible was maintained by the subject while the rod upon which the target was mounted was rotated until the corneal reflex was centered in the amblyopic eye. An allowance of five degrees toward greater esotropia (or less exotropia) due to

the angle between the pupillary normal and the line of sight was made arbitrarily. Since our primary consideration was the change in convergence with the change in accommodation, the error introduced by the assumption that this angle was always equal to five degrees would be negligible except in the differentiation of normal from anomalous correspondence.

Five measurements were made with the subject fixing the target through the plus one diopter sphere while the target was one meter in front of the spectacle plane. The one diopter sphere was removed and five measurements were made with no lens at the one meter fixation distance. The target was moved to 40 cm. and then to 20 cm. in front of the spectacle plane and five measurements made at each of these distances without any auxiliary lens. In each case, the average of the five trials was taken to indicate the squint angle under those experimental conditions. During all trials the subject wore his customary spectacles. This apparatus was used only for amblyopes and the dominant eye was always used for fixation of the reduced Snellen chart.

The subjective angle for infinity was also obtained on one of the instruments described above. If the subjective and the objective angles of squint differed by more than 10Δ, anomalous correspondence was inferred.

Each subject was checked with the after image test (Bielschowsky) as a further aid to the differential diagnosis of normal versus anomalous correspondence.

For all the squinters included in this report, the subjective versus the objective angle and the after image test were in agreement as to the state of retinal correspondence.

Since true binocular cooperation for localization purposes is not presumed to exist in squinters, predicted deviations similar to those made as a result of the phoria in binocular subjects were not made for the squinters.

NORMAL CORRESPONDENCE SQUINTERS

Subject R.B. was a male, 18 years of age. The objective and subjective angle of squint measured 15 prism diopters of exotropia. Normal correspondence was also shown by the after image test. To the subject's knowledge, only one eye was used at a time; he claimed he could use either eye but preferred the right. Visual acuity was 20/15 in either eye. There was no history of surgery. The squint was discovered when he was six years old.

Data supplied by using each eye separately to direct his walking showed that with the right eye the subject walked toward the target

with a deviation of only 1.3Δ too far to the right. Using the left eye, however, the range of his errors was 16Δ to 30Δ too far to the right, with an average error of 21.8Δ toward the right or 20.5Δ more to the right than with his right eye. This would indicate that, after turning the left eye in to fixate the distant target foveally, very imperfect knowledge existed as to the direction of the line of sight of either the right or the left eye. However, the direction and the amount of the average error suggest that the subject was attempting to use the line of sight of the covered right eye as a projection line.

A second male subject, L.H., also 18 years old, was tested. The subjective and objective angles of squint at six meters agreed at about 26Δ of exotropia and the after image test also indicated normal correspondence. This subject represented something of a rarity in that accommodation had no effect on the relative position of the two lines of sight; the ACA was zero.

Subject L.H. frequently used both eyes together and stereopsis was evident. Divergence to the squinting position was common at any fixation distance but was most likely to occur at near since the angle then increased to an exotropia of about 43Δ at 40 cm., and about 60Δ of exotropia at 20 cm. due to the zero ACA. Visual acuity was 20/20 in each eye, but the right eye was preferred for fixation in the squinting position. The age of onset was unknown, and eye surgery had never been performed.

Walking data for the right eye showed that subject L.H. projected the target only 0.9Δ too far to the left; hence, projection with this eye was good. With the left eye fixating, however, he walked 12Δ too far to the right on the average, with a range of 9.1Δ to 15.2Δ toward the right. The average error made when he used the left eye was thus 12.9Δ more toward the right than the right eye error. This amount of error represents about one half of his distance "phoria" or intermittent squint angle. Since this subject frequently uses both eyes simultaneously and fixates with his right eye when monocular vision is used, it is possible that, when the left eye is used alone, projection proceeds parallel to the bisector of the angle of convergence as it would in a normal binocular subject who had a high heterophoria.

ANOMALOUS CORRESPONDENCE SQUINTERS

Eight subjects were used in this portion of the study. Pertinent data on each subject are presented individually and the results of the experiments are then tabulated in Table V.

Subject C.D. was a male, age 22. The objective angle of squint was 23Δ esotropia; the subjective angle, 2Δ exotropia. Visual acuity

Table V. "Walking Experiment" data for eight anomalous correspondence squinters showing the path deviation when one eye was covered and the "peephole" goggles were worn. The amount of tropia and the path deviation are in prism diopters. A plus sign (+) indicates a deviation to the right; a minus (—), to the left.

Subject	Tropia	Preferred Eye	Deviation Right Eye	Deviation Left Eye
C.D.	23 eso	O.D.	+3.5	+6.6
S.G.	30 exo	O.S.	+1.4	+4.8
W.H.	—	O.S.	+0.8	—0.7
D.K.	20 eso	O.D.	+2.6	+3.8
R.L.	32 eso	O.S.	+3.5	+8.4
W.M.	14 eso	O.S.	+1.4	+3.9
J.M.	42 eso	O.D.	+0.7	+3.5
D.W.	21 eso	O.S.	+0.7	+0.5

in either eye was good, but the right eye was preferred. There was no history of surgery: the date of onset was unknown.

S.G. was a female, age 17. About 30Δ exotropia was measured objectively; subjectively, the angle was 10Δ exotropia. Visual acuity was good in either eye and alternation occurred readily, but the left eye was preferred. In 1947 the squint angle had been reduced an unknown amount. She has squinted since birth.

The third subject, W.H., was a male, age 18. He was a post-surgical exotrope whose objective angle varied between 5Δ and 40Δ with accommodation relaxed. Measurement of the subjective angle was not possible as it was impossible for him to maintain a diplopia long enough to make the measurement. Following the surgery six years ago, diplopia was apparent for some months and is still present occasionally. It is interesting to note that, even though acuity was 20/200 in the right eye and 20/20 in the left, projection was remarkably exact using either eye (Table V). His parents noted the exotropia when he was two years old.

Subject D.K., a male, 23 years old, had an esotropia of 20Δ objectively; the subjective angle was 10Δ esotropia. There was no history of surgery. Visual acuity in the right eye was 20/15; in the left eye, 20/25, and the right eye was preferred for fixation. He reports having squinted since birth.

R.L. was a male, 26 years old and an alternating esotrope of 32Δ objectively. The subjective angle was 5Δ esotropia. He showed 20/15 visual acuity in each eye but preferred to use the left eye. There was no history of surgery. He reports having squinted since birth.

Another male, W.M., 18 years of age, measured objectively 14Δ of esotropia and subjectively, about orthophoria. Even though this subject showed a need for a +3.50 diopter sphere on each eye, he wore his spectacles rarely, hence all findings were taken without his spectacles.

Visual acuity: right eye, 20/40; left eye, 20/25. The left eye was preferred for fixation.

The seventh subject, J.M., was a male, 22 years old. Objectively the squint measured 42Δ esotropia; subjectively, about 17Δ esotropia. With the right eye visual acuity was 20/15, and with the left eye, 20/25. His right eye was dominant but alternation occurred readily. Surgery performed five months prior to the time these data were collected had reduced the angle from about 70Δ. This subject also reported having squinted since birth.

D.W., the last subject, was a male, 26 years old. He had an objective squint angle of 21Δ esotropia with a subjective angle of 7Δ of esotropia. Visual acuity in the right eye was 20/400; in the left, 20/20. There was no history of surgery and the squint was believed to have existed from birth.

The data in Table V indicate that each of these subjects projects quite correctly using either eye. This demonstration would eliminate any discussion as to projection: it must proceed very nearly along the line of sight of the eye used regardless of the squint angle. Certainly, projection could not proceed parallel to the bisector of the angle of convergence as it appears to in normal binocular subjects.

ONE-EYED SUBJECTS

Two one-eyed individuals were included in this study because it was felt that responses obtained from subjects in whom there was no possibility for binocular cooperation might aid the comparative analysis of squinters who rarely, if ever, use both eyes together in the same sense as do binocular individuals. Measurements on these subjects were limited, of course, to visual acuity and motility of the remaining eye.

Our first subject, D.R., was a female, 22 years old, whose left eye had been destroyed by a hand grenade five months prior to this experiment. Visual acuity without spectacles was 20/15 in the right eye and motility of this eye was normal.

When this subject attempted to walk toward the target 1,000 yards away, she made an error of 7.4Δ toward the right. Projection experiments using targets placed 40 cm. from the subject's nose were performed later by this subject, the results of which indicated that projection at near was rather precise. These data will be presented in a later paper.

"Convergence" for a target on the midline 40 cm. in front of the subject would demand a turn of this right eye of about 7.5Δ toward the left, but this near target was localized correctly. This might be interpreted to mean that this subject, prior to the accident, possessed an

ACA of about six and that this ACA relationship, coupled with orthophoria at distance, allowed her to project along the bisector of the angle of convergence at near. However, such an explanation would not allow for the error in projection at distance as shown by the walking experiment.

A second explanation could be based upon the assumption that with the loss of one eye a whole new projection pattern was necessary. An error in projection at near would be recognized readily by the subject and therefore correct projection at near would be learned first: small distance projection errors would be unrecognized and hence might go uncorrected. Since the turn of the right eye at near was about 7.5Δ toward the left, we might expect an error at distance of about 7.5Δ toward the right. This one-eyed subject was developing a projection pattern similar to that of a squinter: projection depended upon a knowledge of the direction of the line of sight of the remaining eye. In time we might expect reasonably correct projection for distant targets, also.

Subject D.W. had lost his left eye two years prior to the experiment. At the time the data were collected, he was 24 years old. Visual acuity with his spectacles was 20/15 and motility was normal. Walking data showed an error of only 0.6Δ toward the left. Since experiments at near also indicated good projection, it is probable that D.W. had learned a new projection pattern which also depended upon a knowledge of the direction of the line of sight of the remaining eye. The effects of any previously existing ACA relationship were now ignored.

SUMMARY AND CONCLUSIONS

Binocular subjects under normal circumstances appear to use the mean direction of the lines of sight of the two eyes in the absolute or egocentric localization of objects around themselves. This mean direction is often described as the bisector of the angle of convergence of the two eyes. It should be kept in mind, of course, that this "bisector" actually bisects the angle of convergence only under circumstances similar to those described in the main body of this paper, i.e., when convergence is symmetrical. The data presented in this paper do not preclude the possibility that projection in binocular individuals may proceed along the line of sight of the fixating eye: data to be presented in a subsequent report should help clarify this point.

As pointed out earlier, binocular cooperation for localization purposes is not presumed to exist in squinters, hence it would hardly be reasonable to expect such subjects to use the bisector of the angle of convergence as a clue to direction. A normal subject who has a high phoria does not use his eyes dissociated but uses them binocularily with

the phoria compensated for via fusional convergence, and he sees both the dextrocular and sinistrocular images in the same direction. If he were to wear an occluder over one eye to make himself similar to a normal correspondence squinter who suppresses vision in one eye, the large deviation of his covered eye would at first cause errors in localization. This phenomenon was demonstrated by subject L.H., the intermittent exotrope, when he fixated with the normally deviating eye. Subject L.H. projects parallel to the bisector of the angle of convergence when the normally non-fixing eye is used.

If, however, the occluder were worn constantly over one eye until the subject had learned to project correctly with the uncovered eye, and then the occluder were shifted to cover the "trained" eye, one might expect him to see objects in the direction in which the "trained" eye was pointing. Subject R.B. illustrates this phenomenon rather well. Clinically this phenomenon is rather simple to elicit in monocular squinters who have normal correspondence. After first occluding the "poor" or normally non-fixing eye, the patient is asked to put his finger tip on a small target within arm's reach. This must be done with a sudden arm movement in order to prevent a correction being made. It will be noted that most subjects do this quite accurately. If now the normally fixing eye should be occluded and the same directions given to the subject, an error in localization will result. The subject now puts his finger tip on a point removed from the target in a direction which corresponds rather well to that point toward which the now covered but normally fixating eye is pointing.

Normal correspondence squinters are most frequently monocular squinters. Projection in these subjects proceeds parallel to the line of sight of the normally fixing eye regardless of which eye is used except in those subjects who use both eyes together a reasonable portion of the time.

It is conceivable that, if a normal binocular individual with a high phoria had an occluder switched from one eye to the other at regular intervals, he would learn to project correctly with either eye. This is analogous to the alternating squinter who, incidently, most commonly exhibits anomalous correspondence. Such an individual probably would learn to project along the line of sight of the eye used since no other projection line seems evident. In Table V, the data for anomalous correspondence squinters indicates that these squinters do indeed project along the line of sight of the fixing eye. The relatively small errors exhibited by these subjects implies that under normal two-eyed conditions they may depend upon information obtained from the opposite or non-fixing eye.

It is interesting to note that, in the case of the anomalous correspondence squinters used in this experiment, projection was rather accurate with either eye, even when visual acuity in the two eyes differed markedly. Hence, even monocular squinters who have anomalous correspondence appear to have good projection in either eye.

Projection in normal binocular individuals appears to proceed parallel to the "bisector" of the angle of convergence; in one-eyed subjects, parallel to the line of sight of the remaining eye; in normal correspondence squinters parallel to the line of sight of the eye preferred for fixation; and in anomalous correspondence squinters, parallel to the line of sight of the eye used.*

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PHYSIOLOGICAL BASIS FOR DISCOMFORT GLARE*

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Discomfort glare is the capacity of a given distribution of brightness in a person's field of view to produce discomfort. For example, the addition of a single glare source in a given environment may bring discomfort and the removal of such a source will immediately remove the discomfort.

THE MECHANISM OF PAIN

A change in environment which may be mechanical, chemical or thermal may stimulate a receptor neuron for pain whose endings are in or near muscular or cutaneous tissue. The receptor neuron carries the impulses to the spinal cord or the brain stem where it synapses with a connector (2nd order) neuron. This neuron crosses to the other side of the spinal cord and ascends to the thalamus, where it synapses with a central neuron. The central neuron then carries the impulse to the cerebral cortex where it is registered as pain. This is a simplified description of pain pathways to the cortex.

There are a number of different kinds of receptors in the cutaneous area. Some nerves are bare and free at their terminal point while others display various types of end organs. It is this plus experimental evidence which suggests that different types of nerve endings are in part responsible for different sensations such as heat, cold, pressure and pain. The receptor neurons responsible for pain are thought to be those having bare nerve endings.

When the pain impulses enter the spinal cord or brain stem the pattern of impulses may be altered before being transmitted to higher centers. Such phenomena as summation and inhibition may be implemented here or after the impulses reach the higher centers.

Referred pain is felt in a part other than that to which the stimulus is applied. For example, a toothache may be so diffuse that it is difficult to determine which tooth is responsible for it. It is usually possible to demonstrate that the irritant impulses from the source of stimulation involve the same segments of the spinal cord as do the impulses con-

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cerned in the referred phenomena. The two nerves are adjacent in the central nervous system. Occasionally there are examples of referred pain where it is not possible to demonstrate this.

DISTRIBUTION OF SENSORY FIBERS TO ORBITAL AREA

The eye, scalp and orbital area are supplied with sensory fibers from the fifth cranial nerve. The neck and part of the face is supplied by sensory fibers from the second and third crevical plexuses of the spinal cord. These nerves supply most of receptor organs for pain above the shoulders.

Magendie[1] demonstrated that the retina is insensitive to pain and that in man section of the optic nerve is not painful. The sheath surrounding the optic nerve does contain pain fibers as evidenced by the pain accompanying eye movements associated with retrobulbar neuritis.

The cornea is richly supplied with pain fibers. Most authorities agree that cold spots are present on the cornea. As for the existence of a touch sense there is conflicting evidence. There is no heat sense in the cornea. The conjunctiva is sensitive to touch, pain and cold. Also the areas bordering the lids and the lacrimal caruncle are sensitive to heat. The sclera and uveal tract are supplied with sensory fibers of pain.

The iris is very sensitive to pain: traction or pressure such as might occur during surgery may be very painful. Traction on the extraocular muscles will produce discomfort and pain as will cutting or piercing with a scalpel or needle.

PHOTOPHOBIA

Photophobia literally means fear of light, but is usually interpreted as a condition of actual pain in the eye induced or aggravated by light. The closing of the eyelids when the cornea is exposed to cold is sometimes referred to as photophobia although light is not a factor in this instance.

Von Frey, Nagel and Fuchs[1] avoided the pain of light induced photophobia by using homatropine which paralyzes the sphincter muscles of the irides.

Seigwart[2] found that only rays from the visible spectrum produce photophobia and that the reaction to spectral colors was determined by their relative luminances and the consequent effect on pupillary constriction.

Vogt and Seigwart[1] demonstrated that in 46 absolutely blind eyes, covering a wide variety of conditions, there was absolutely no photophobia or blinking on direct exposure to light. In three patients with the consensual reflex preserved the blind eye reacted with pain when the seeing eye was illuminated. This indicates that the pupillary constric-

tion is important to the production of photophobia.

The evidence thus far demonstrates that photophobia cannot occur without the functional integrity of either the consensual or the direct light reflex. The fibers of the fifth nerve must also be intact in order to convey pain impulses from the ciliary body and iris.

Krause[2] in 1896 discovered that removal of the gasserian ganglion abolished photophobia from the eye on the operated side but not from the other eye. Peters[2] emphasized that trigeminal hyperirritability must be an essential factor in the pain caused by the pupillary reaction.

Lebensohn[1, 2] suggests that the vasodilation of the trigeminal pupillary reflex was the sensitizing factor that made the pupillary light reaction painful. According to Lebensohn the trigeminal axon reflex produces vasodilation of the capillaries via the release of a vasodilator substance similar to histamine. It also produces hyperalgesia (lowering of the threshold of sensory receptors in a certain area). Irritation of the fifth nerve causes a pupillary constriction the trigeminal pupillary reflex —which is probably due to a reflex vasocongestion of the iris.

In support of this theory he found that 1:1000 epinephrine (vasoconstrictor) relieved photophobia in chronic conjunctivitis, corneal disease and iritis.

Lebensohn also performed the following experiment: he determined for several subjects with a pathological involvement of the anterior segment of the eye the threshold of photophobia by using a 100 ft.-c source and crossed polaroids in front of the photophobic eye. The affected eye was then treated with two instillations of epinephrine (either 1:1000 or 1:100) two minutes apart and the measurement of the threshold of photophobia was made ten minutes apart. Other drugs were used; neosynephrine (10%), homatropine (5%), atropine (1%) and inhilation of 15 drops of trichlorethylene (chlorylen). All drugs raised the threshold for photophobia.

Eckardt, McLean and Goodell[3] have studied the light induced photophobic responses of normal subjects (free from inflammation of the iris and ciliary body) by providing continuous exposure of a light source, and using an increase in blink rate as the measure of the intensity of photophobia.

The stimulus was a bright source of 23 candles which was exposed for 20 seconds and the rate of blinking during this period was determined. One eye at a time was used because one eye was manipulated by applying an irritant to the cornea, or by instilling a drug and the other eye was kept normal as a control.

The following findings were reported:

(1) The blink rate is increased by
   (a) A foreign body in the cornea of one eye when light is applied to the same eye.
   (b) Surface irritation of the cornea of one eye with drugs, when light is applied to the same eye.
   (c) A cycloplegic in one eye when light is applied to the same eye.
   (d) A cycloplegic in both eyes when light is applied to either eye.

(2) When both eyes are homatropinized the blink rate is increased for each eye, and then when an irritant is applied to one eye the blink rate for this eye is further increased.

(3) An anesthetic applied to the cornea of one eye reduces the blink rate for that eye to practically zero.

(4) The increase in blink rate produced by a surface irritant is not affected by adrenalin, but is reduced by a light surface anesthesia (½ % tetracaine).

(5) A person with a complete section of the fifth nerve on one side exhibits no increase in blink rate following irritation of the cornea on that side.

(6) Subjects with Argyll-Robertson pupils show no increase in the blink rate following irritation of the cornea and/or the instillation of homatropine.

(7) Injection of salt solution into the frontalis muscle on one side increases the blink rate when the eye on the same side is exposed to light.

The fact that binocular instillation of homatropine increases the blink rate eliminates pupil constriction as an essential part of the mechanism for involuntary blinking. In case of normal irides contraction could stimulate the fifth nerve endings in the iris and this excitation like excitation of other branches of the fifth nerve could add to the blink rate.

If the above interpretation of the facts is correct the further fact that irritation of the cornea in case of Argyll-Robertson pupils causes no increase in blink rate must be interpreted to mean that the lesion which blocks the pupillary light reflex also blocks the afferent pathway from the cornea to the center controlling involuntary blinking.

In all of this work it must be kept in mind that irritating or anesthetizing one cornea does not produce a differential rate of blinking in the two eyes. Each blink in each eye is associated with a blink in the opposite eye.

A puzzling feature about the results is the difference in the binocular blink rate attained by applying light to the different eyes when one of the corneas is either irritated or anesthesized. Each optic tract contains fibers from both eyes, and it is difficult to see how pain impulses from the cornea of one eye can summate more effectively with impulses from the retina of the same eye than with impulses from the opposite retina.

Eckardt, McLean and Goodell[3] concluded that photophobia is the result of light stimulation and irritation of the ophthalmic branch of the fifth nerve. They explained the neural mechanism like this. Afferent impulses via the mesencephalic root of the fifth nerve set up an excitation of this portion of the central nervous system (i.e., the mid brain) which in turn lowers the threshold for impulses received, and with the light stimulus via the optic nerve acting as a trigger mechanism, the interpretation of these impulses is greatly enchanced. Also it is a well recognized fact that painful sensations from the fifth nerve area, including the cornea, are mediated by the spinal tract of the fifth nerve and its nucleus. This pathway must also be considered in the final analysis.

In an irritable eye the ciliary body as well as the iris can be reflexly stimulated by applying light to the retina. Lebensohn[2] found that turning on a 200-watt bulb near photophobic patients resulted in an increase in —0.25 to —0.75 diopters to bring their acuity to normal. This means that the ciliary body has been reflexly stimulated by the light.

Although the investigations just described do not arrive at exactly the same conclusion regarding the mechanism of photophobia they both confirm that the integrity of both the fifth nerve and optic nerve must be maintained in order to induce photophobia. This is an important point.

DISCOMFORT

Discomfort and pain form a continuum and discomfort can be considered as a mild degree of pain. Any stimulus that is considered uncomfortable will become painful if the stimulus is increased sufficiently in intensity. Consequently the same neurological and physiological mechanisms are thought to subserve both experiences.

Discomfort resulting from muscular strain and contraction is thought to be the primary cause of discomfort associated with glare. A good example of "muscular pain" is that which is experienced with a muscle cramp. Anyone who has experienced this will agree that it can be very painful. This experience of a muscle cramp goes through the following stages: uncomfortable, painful and then uncomfortable again

before disappearing entirely. This also illustrates the continuum of discomfort and pain.

There is considerable evidence illustrating the production of discomfort via the muscles of the eye and head region. Eckardt, McLean and Goodell[3] duplicated refractive errors by wearing appropriate lenses and concluded, first, that headaches resulting from hyperopia, astigmatism and muscle imbalance are the result of sustained contraction of the intra-ocular muscles associated with excessive accommodative effort, and second that they are secondary to the unusually great and sustained extra-ocular muscle contraction resulting from the effort to maintain fusion.

They also took electromyographic recordings of a patient with convergence insufficiency and of two normal patients wearing vertical prisms. In each instance the symptoms which developed (discomfort) were accompanied by increased muscle potentials from the muscles of the scalp and neck. This work indicates that sustained contractions of the muscles of the scalp and neck contribute to the headaches associated with extra-ocular defects. People with tensions (nervous) are more prone to develop symptoms from refractive errors and muscle imbalances.

Fugate and Fry[4] have reported the effect of paralyzing the sphincter muscle of the iris on discomfort produced by flashes of light. In their work the subject was first exposed to an adaptation stimulus for at least thirty seconds. Then momentary stimuli (flashes of light) were presented in volleys involving one second on, one second off, one second on, one second off, one second on, and then five seconds off before the next volley. Each subject was required to observe a minimum of three such volleys before attempting to describe the subjective experience. With this procedure the subjects could vary the intensity of the stimuli until it was determined to be at the border line between comfort and discomfort (BCD).

Then homatropine was used to determine the rôle of pupil constriction in producing the discomfort associated with a brief exposure to light. Homatropine paralyzes the sphincter muscle of the iris by blocking the myoneural junctions which abolishes the response of the pupil to light. Two drops of two per cent aqueous solution of homatropine were instilled into the left eye every ten minutes until six drops had been instilled. One hour after the last instillation of drops the BCD brightness was determined. Drops were then instilled into the right eye in the same manner, and an hour after the last drops had been instilled into the right eye an attempt was made to determine the BCD brightness.

The results of this experiment show that the paralysis of the left

eye has little or no effect on the BCD brightness but as soon as both are paralyzed, it becomes impossible to determine the BCD brightness.

One subject, G.F., found no discomfort at all associated with the brightest momentary stimuli available with the apparatus (1,000,000 trolands) immediately following paralysis of both irises: but when he went outside into the open and faced the sky, this produced an irrepressible blinking and squinting and eventually tearing. Accompanying these symptoms there was a definite discomfort which could be avoided by occluding one eye entirely and part of the field of the opposite eye or by wearing neutral filters over the opposite eye. The experiment was carried out on the first of September and, although the brightness of the sky on this particular day was not measured, available data on sky brightness for a clear day indicate that the sky brightness is of the order of 2.5 lamberts. With an 8 mm. pupil this would produce a retinal illumination of 400,000 trolands. The failure to experience discomfort with the brightest momentary stimuli provided by the equipment is probably dependent upon the limited extent and duration of the exposure.

Subjects J.F. and N.B. were able to detect a mild form of discomfort with paralysis of both irises when maximum size and brightness were used for the momentary stimuli, but it was qualitatively different from the type of experience which had been previously used in identifying the borderline between comfort and discomfort. These same subjects reported severe discomfort when going outside.

The sort of discomfort which the subjects experienced with homatropinized eyes out of doors differs from the experience of discomfort which is experienced just above the borderline between comfort and discomfort in having an experience of tenseness and desire to squint as the predominating factor. This qualitative observation points to the conclusion that it is necessary to consider two factors: one, the constriction of the pupil, and the other the activity of the muscles associated with the act of blinking and wrinkling of the brows and skin of the forehead. There is also the factor of the general increase in tension of the extraocular muscles.

The data for three of the subjects show that the threshold for discomfort associated with the other muscles of the orbits is higher than that for the sphincter of the iris, and this is of some value in establishing the fluctuation of the pupil as a useful index of the borderline between comfort and discomfort.

A discussion of the causes of discomfort would not be complete without mentioning a group of factors which are frequently referred

to as psychological. Emotional stresses such as worry, anxiety and nervous tension will in all probability lower the discomfort threshold, as will distractions which impair concentration and induce a sense of frustration. Factors such as these are extremely difficult to assess and evaluate but they cannot be ignored.

DISCOMFORT STIMULI

Changes that may occur with the addition of a glare source to the environment, may trigger the discomfort glare mechanisms I have just reviewed. The sudden addition of a glare source to the environment will cause the pupil to constrict. This glare source combined with normal eye movements will result in a continuous change in the distribution of light on the retina and thus a continuous fluctuation of the pupil. As has been described the constriction of the pupil can cause mild to severe discomfort.

The addition of a glare source may result in "veiling glare." This means that stray light from the glare source will fall in the macular area and thus make it more difficult to see the object of regard. This veiling glare will make a person get closer to his work in order to see it better, thus increasing both the amount and variability of accommodation and convergence. Also the posture of the body, head and neck may change to an uncomfortable position. All of these changes will result in an increase of sensory stimulation in the muscles involved, thus producing or contributing to discomfort.

Even if the glare source is not sufficient to reduce the visual acuity it can be very distracting. How often have you read a glossy page and found a very annoying glare on the page? The usual procedure then is to rearrange yourself and/or your reading material to eliminate it. In so doing all or at least some of the aforementioned changes (accommodation, convergence and posture) will probably occur and contribute to discomfort. If you choose to try to ignore the glare source the psychological element of frustration and difficulty in concentrating is introduced.

The glare source may also produce an after image, and combined with normal eye movements may result in the production of an after image on or near the macula. The resultant decrease in visual acuity may then contribute to the preceding syndrome.

Another change likely to occur with the introduction of glare is frowning or grimacing. This action is associated with annoyance, a desire to decrease the light entering the eye and/or to eliminate the glare source from the field of view. Here of course muscular contraction results in direct sensory stimulation producing discomfort.

It has been discussed how a light stimulus may actually induce pain or discomfort when accompanied by severe pathological conditions of the eye. There are other factors, pathological and non-pathological, which may cause a sub-photophobic condition. This is a condition where actual photophobia does not exist, but the threshold for pain of the fibers of the fifth cranial nerve and perhaps the second and third spinal nerves of the cervical plexus, is below normal. If hyperirritability existed, then a glare source could produce discomfort in the same manner as photophobia is produced. The following factors individually or in combination may contribute to the lowering of the sensory pain threshold of the aforementioned nerves.

(1) Uncorrected refractive errors such as: hyperopia, astigmatism, high myopia, anisometropia and presbyopia.
(2) Extra-ocular muscle imbalance.
(3) A chronic, subacute, ocular pathology such as conjunctivitis or a low grade allergic reaction.
(4) A low grade general toxemia.
(5) Unfavorable environmental conditions such as improperly regulated heat, humidity and drafts.
(6) Insufficient or poor distribution of illumination for the task at hand.
(7) Emotional or nervous tensions, which may be a function of the individual and/or the task he has to perform.

The glare source in this case would act as the "straw that broke the camel's back," in that these conditions may not in themselves cause discomfort until summated with a glare source.

Conditions such as these contribute to the variation from individual to individual with respect to the variation of the borderline between comfort and discomfort.

It should be noted that all of these factors may summate to produce discomfort, and that any one may be the "last straw." For instance a refractive error may not cause discomfort until summated with some of the preceding factors; and correcting the refractive error may completely eliminate the discomfort. Or it may become necessary to manipulate more than one factor to make the environment comfortable.

The foregoing may explain in part how a relatively small refractive error may cause symptoms which appear to be all out of proportion to the error involved. Correcting this error may then relieve relatively severe asthenopic symptoms by eliminating just one of several contributing factors, and thus rendering the other contributing factors subthreshold as far as discomfort is concerned.

EXPERIMENTAL APPROACHES TO THIS PROBLEM

Some of the available information has been analyzed relative to tentative conclusions regarding the mechanisms of discomfort glare. Here are some possible avenues for further investigation:

(1) Electromyographic recordings could be utilized. This involves inserting an electrode directly into the muscle to be analyzed.

(2) Anesthetize the muscles involved and evaluate subjective data under adverse conditions, or perhaps make use of an individual who has had all or part of the fifth cranial nerve sectioned or destroyed.

(3) Utilizing the blink reflex as a criteria of discomfort is probably the easiest method available. Although there is some controversy regarding the validity of the blink reflex as a criterion of fatigue and performance. Part of this problem lies in the manner in which the experimental variables have been manipulated.

It is proposed that gross changes in the experimental parameters be introduced. Significant changes in the blink reflex from small changes in lighting conditions should not be expected. Our present knowledge of the blink reflex indicates that we should be able to make lighting conditions extreme enough to induce significant changes. The principle is illustrated by the use of prisms[5] and lenses[6] to produce artificial refractive errors and muscle imbalance. The blink reflex can probably be made more sensitive to refractive errors, muscle imbalance and poor lighting by the use of drugs to irritate the cornea. The principle of making the blink reflex a more sensitive indicator of tension is illustrated by the experiments of Eckardt, McLean and Goodell.

The importance of the blink reflex as an index of discomfort is its usefulness in the study of the effects of steady stimulation. In the case of steady stimulation pupil fluctuations can be recorded but they are difficult to interpret, but the frequency of blinks is easily determined.

SUMMARY

(1) Pain and discomfort stimuli are conducted over sensory neurons and are subject to change in the central nervous system.

(2) It is necessary for the optic and fifth cranial nerves to be intact before the pain or discomfort of light induced photophobia can be produced.

(3) The inducement of discomfort by muscular strain, tension and contraction, in the orbital and head region has been illustrated.

(4) Introducing a glare source to the environment can produce discomfort via an increase in the tension of the muscles of the head, neck

and orbital regions.

(5) Discomfort associated with uncorrected refractive errors, and/or ocular muscle imbalance, is probably subserved at least in part by the same physiological mechanisms as discomfort glare.

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TRANSACTIONS OF THE ACADEMY
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A department devoted to announcements, reports, appointments, organization data, news, professional problems and ideals, as these relate to the Academy.

CHAPTERS ELECT OFFICERS

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BILATERAL CORRELATION OF RESIDUAL ASTIGMATISM*

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INTRODUCTION

Residual astigmatism, variously called physiological, intraocular, or lenticular astigmatism, is the difference between the astigmatism in the spectacle plane attributed to the effectivity of the ophthalmometrically measured corneal astigmatism and the total astigmatism of the eye as measured by any of several routine clinical techniques. Because of the small variance in the amount and axis of residual astigmatism, values of the order of 0.50 D. $\times$ 180° have been variously recommended[1] as constants or standard allowances in the computation of the expected or predicted total astigmatism from the ophthalmometrically measured astigmatism. A very commonly employed rule-of-thumb for such computations is that of Javal[1] which states that

$$T = 1.25C + R \qquad (1)$$

in which

T = the total astigmatic correction
C = the corneal astigmatic correction
R = the residual astigmatism

Inasmuch as this formula is based on the statistical regression of T on C, the formula theoretically is not reversible. By the same token R is derived from the regression line rather than as a mean of a group of individually computed differences between "1.25C" and "T." However, because of the known low variance of R in comparison to C or T, the errors in assuming reversibility are clinically quite negligible.[2] On this assumption it becomes permissible to arrange the formula as follows

$$R = T - 1.25C \qquad (2)$$

and from this to compute for each eye a value which we can identify as its own apparent residual astigmatism factor. Naturally any measurement errors in T or C in this procedure will result in variations of the apparent residual astigmatism factor for the eye in question.

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†Optometrist, Ph.D., Director of Division of Optometry, Fellow, American Academy of Optometry.
‡Optometrist, American Optometric Foundation Research Fellow.

The present report is concerned with the question of whether the apparent residual astigmatism factors for the two eyes of a pair are correlated.

PROCEDURE

The clinic records for this study were taken from the files of two optometric practices.* The case records were originally selected for another purpose and consisted of records of patients whom the optometrists had examined three or more times in a period of a few years. Only the data from a single examination were used from the series of records for each patient. On the assumption that a second examination was likely to show greater reliability and validity in the astigmatic findings, the second examination was arbitrarily selected from each series except when the subjective and retinoscope cylinder findings differed from each other, in which case the third examination record was used if it showed higher agreement. Where actual agreement was not so obtainable, the cases were not included. Only three such records were encountered.

The ophthalmometer readings from the same examination records were used to obtain the individual C values in the preceding formula.

The few records showing the astigmatic axis of either the ophthalmometric or the total astigmatism more than 30° from the vertical or horizontal were not included. All of the remaining records were then arbitrarily considered to have their principal meridians in the vertical and horizontal for the purpose of this analysis and for the application of the above mentioned formulas.

RESULTS

Scatterplots showing the R values of the right eyes plotted against the R values of the left eyes are shown in Figure 1 for the total group of 148 subjects. The correlation coefficient computed by the product moment formula[3] is +0.62.

To determine whether or not differences in total astigmatism might be related to the apparent residual astigmatism the total group was subdivided into three categories, those showing differences of 0.75 D. or more, those showing differences between zero and 0.75 D., and those showing no difference. The corresponding correlation coefficients for the three groups are +0.54, +0.77, and +0.56, respectively.

In Figure 2 are shown the R values of the right eyes plotted against the age reported at the time of examination. No apparent trend of R with ages is indicated.

*George Meyer, O.D., Adrian, Michigan, and Ralph LeDrew, O.D., Edmonton, Alberta, Canada.

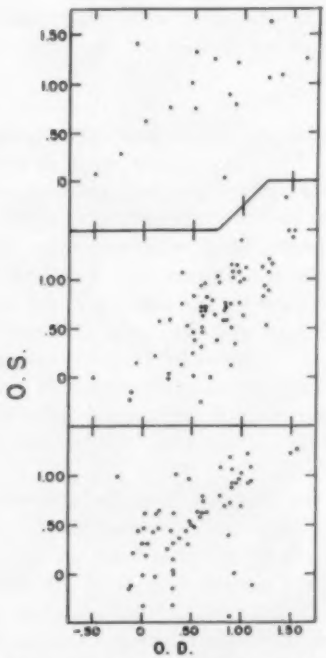

Fig. 1. Scatterplots showing the relationship of the residual astigmatism (R) of the left eye (O.S.) to that of the right eye (O.D.) in three groups of subjects classified according to differences in total astigmatism in the two eyes. The top figure represents 17 subjects with differences in astigmatism of 0.75 D. or more: the middle figure represents 68 subjects with differences of total astigmatism between 0.75 D. and zero: the bottom figure represents 63 subjects with no difference in total astigmatism. The d'optric values represent the power of the cylinder with axis horizontal (180°) which would correct the residual astigmatism.

DISCUSSION AND CONCLUSIONS

The lack of any significant difference in the correlation cofficient of the right and left eye R values for the most anisometropic and the least anisometropic groups suggests that the residual astigmatism is independent of the difference in total astigmatism. This means that the ophthalmometric findings may be used to derive practical information concerning the total astigmatism that can not be derived from the application of Javal's rule for a single eye. For example, if the ophthalmometer reading shows

O.D., 44.00 @ 180 45.00 @ 90
O.S., 44.00 @ 180 44.50 @ 90

it may first of all be predicted according to formula (1) that the total astigmatism would be corrected by

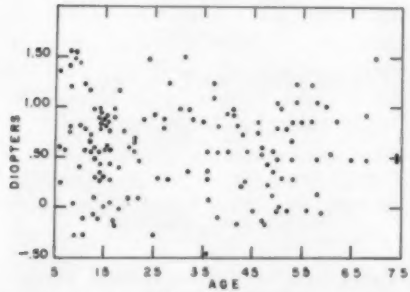

Fig. 2. The average residual astigmatism (R) for each pair of eyes plotted against the age given by the subject at the time of the measurement.

O.D. —0.75 D.C. X 180
O.S. —0.12 D.C. X 180

If now the total astigmatism of the right eye is reliably measured to be —0.25 D.C. X 180, according to the observations reported here, the predicted value for the left eye would be more accurately revised to show a value nearer —0.37 D.C. X 90.

The fact that the cases in the intermediate range of astigmatic anisometropia (between 0.00 and 0.75) show the higher correlation of +0.77 is not easily explained except as a chance variation. However, from a practical point of view, it does contribute to the probability that the other correlation coefficients of +0.54 and +0.56 are lower than the true values that would be obtainable in larger samples, and hence offers support to the reliability of the practical clinical application described above.

The present data do not indicate that any variations in residual astigmatism occur with age.

The practical application that may be drawn from the foregoing is that the total cylinder of one eye can be predicted more reliably when the total cylinder of the other eye and ophthalmometer readings of both eyes are known. The method mentioned here for predicting total astigmatism from ophthalmometer findings may prove to be a useful addition to present techniques for relating refractive tests.

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A.O.A. HOLDS SUCCESSFUL CONGRESS

Serious inquiry into the nature of problems facing optometry, coupled with mature judgment and professional restraint, marked the 1957 Annual Congress of the American Optometric Association, Los Angeles, June 23-26. If this meeting was distinguished from some that preceded it, it was due to the absence of boastfulness and hysteria. In Los Angeles only a small number were "tilting-windmills" and on the few occasions this was attempted, a serious body of delegates put an end to the nonsense, firmly and quickly.

Officers and delegates fully realized the opportunities and problems which are ahead and they faced their responsibilities with optimism and determination. Realizing the need for action in serving both the public and optometrists, the A.O.A. put its house in order so that problems could be properly studied and new opportunities could be met.

More than 1,000 persons registered at the 60th Annual Congress of the A.O.A., Statler Hotel, for the four day meeting.

The announced reorganization of officers and trustees was approved and the following were elected. Dr. Lester H. Sugarman, Meriden, Connecticut, president. Dr. Hoyt S. Purvis, Jonesboro, Arkansas, president-elect. Dr. Rupert E. Flower, Visalia, California, immediate past-president. Dr. P. M. DeVere, Morgantown, North Carolina, vice-president. Dr. H. Ward Ewalt, Pittsburgh, secretary-treasurer. The officers and the following members constitute the new board of trustees. Dr. Nelson E. Abrahamson, Sr., Cleveland; Dr. Harold M. Fisher, New York City; Dr. Roger O. Lindquist, Minneapolis, and Dr. Richard C. Schiller, Marshalltown, Iowa.

After reviewing a number of major projects planned for the coming year, the delegates voted an increase in annual dues from $30 to $40. This increase will go into effect January 1, 1958. The delegates voted to hold the 1959 meeting in Dallas. The 1958 meeting is to be in Washington, D. C.

The 60th Congress was dedicated to Dr. Ernest H. Kiekenapp, 67, Minneapolis, who retired after serving as secretary of the A.O.A. since 1922. Dr. Kiekenapp now receives a lifetime pension and was elected secretary emeritus. He was also awarded an honorary life membership in the A.O.A. During the banquet period he received high praise and a number of gifts.

The educational program was varied, dealing with public and private health programs; the role of vision in highway safety; the economics of optometric practice, as well as a session devoted to the work of military optometrists. In addition several important original papers were read.

The Los Angeles Congress Committee did a masterful job of both arrangement and convention management. All programs went forward smoothly under the leadership of Dr. D. LeRoy Leatart, Long Beach, general chairman of the committee.

With the assured support of all State Optometric Associations and with a successful convention just concluded, the new A.O.A. officers and trustees may look forward towards a year of accomplishment for optometry. The effects of social trends upon the profession; the impacts of interprofessional relationships; the advancements in practice management; aspects of professional economics, and a variety of health legislation impinging upon optometry will provide the major tasks for the officers and committees for the coming year. With full cooperation progress seems assured.

CAREL C. KOCH

SPECIAL REPORTS

VACUUM-COATED SUN-GLASS LENSES*

Eduard Bosshard†
Zurich, Switzerland

In recent years protective lenses for sun-glasses have been manufactured by the deposition of thin layers of material upon the lens by means of evaporation in high vacuum. Because of the advantages that these lenses possess, it is to be expected that they will play an increasingly important role in the future and that they will be widely used throughout the world.

PRINCIPLES OF APPLICATION

The material to be exaporated is heated to its melting point and beyond in a vacuum of 1/100,000,000 of normal atmospheric pressure, maintained in a small electric furnace. The evaporating material diffuses very readily in the vacuum and condenses on the wall of the evacuated vessel. If the objects upon which thin layers are to be deposited —in this case lenses for sun-glasses—are placed in a suitable holder between the evaporating material and the walls of the vessel, the material will be deposited in a very thin layer on the glass surfaces facing the point of evaporation.

If these layers are to afford protection to the eye against light or glare, and also harmful or injurious radiation, they must have definite absorption characteristics. Certain metal oxides have these characteristics and are used extensively for coating such lenses. Vacuum-deposited metal oxide layers have, however, too high a refractive index compared with glass and this causes very disturbing reflections to occur which have to be eliminated. This is achieved by applying at least one additional layer of a lower refractive index on top of the metal oxide layer, so as to exert an anti-reflection effect.

The special absorption properties required of the evaporated layers depends upon the task which a particular sun-glass lens is required to fulfill. For example, a protective glass designed for general use should satisfy the following requirements:

1. partial suppression of visible light,

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†Certified Ophthalmic Optician. Member, Swiss Association of Ophthalmic Opticians. Member, Association of Scientific Ophthalmic Opticians (Germany).

2. complete absorption of ultra-violet radiation for wavelengths less than 3200 A_μ, and
3. reduced transmission for short-wave infra-red radiation.

While the first and second of these requirements can be met with comparitive ease by the vacuum evaporation method, the reduction of transmission for short infra-red radiation presents some difficulty.

In spite of this, a number of lens manufacturers have succeeded in achieving the required reduction by using special methods. It is clear that lenses for sun-glasses coated by the evaporation process must come up to the same standards that have already been established for the best types of protective glasses of conventional manufacture, including those covered with fused colored glass. In addition to this, distributors insist on being supplied with sun-glasses meeting established specifications, at least to the extent that the degree of absorption (expressed as a percentage), the transmission curve and the color of transmitted light are such that the user will not detect any irreglarities, or at least is not inconvenienced by them.

The writer's experience has shown that these requirements have been obtained in respect to the sun-glass lenses coated in the factory of Geraetebau-Anstalt Balzers by means of the evaporation process invented and developed by them. The main difficulties to be overcome in this process are due to the fact that the layers to be deposited on the lenses are extremely thin (about 2000 A_μ in thickness) and that the thickness of the layers must be absolutely uniform within tolerances of not more than $\pm$ 1%—that is, within 20 A_μ or 0.000002 millimeter. These standards cannot be maintained without the use of extremely accurate optical methods, based on optical interference effects which permit of precise adjustment of the various stages in the evaporation process, and maintenance of the thickness of the layer under strict control and within the specified tolerances.

The hardness of the layers applied by the evaporation process to the lenses is not less than that of the crown glass serving as a carrier, and the resistance to chemical attack and to mechanical wear is high. Satisfactory bonding of the coatings to the glass surface and perfect quality of the layers depends on the cleanliness of the lenses before treatment and also on the optical quality and condition of the surfaces. Only lenses with optically ground and polished surfaces should be treated by the evaporation process. Before coating, the lenses must be carefully cleaned by both mechanical and chemical methods with a final rinse in alcohol of high purity. The cleaned lenses are then placed in special holders inside the vacuum chamber. These holders are rotated

during evaporation to ensure uniformity of the coatings. The holders themselves must be made of metal, as non-metallic materials such as plastics would prevent the attainment of the very high vacuum required for the process.

ADVANTAGES IN THE EVAPORATION PROCESS

The evaporation process for the application of extremely thin layers to spectacle lenses has been developed to such a degree that protective lenses so manufactured are no longer inferior to conventional lenses of the highest quality and may be superior in certain respects, namely: (1) Absolute uniformity of absorption from the center to the edge of the lens, irrespective of its dioptric power, without any increase of either the thickness or weight of the coated lens. (2) Exact duplication of the specified degree of transmission and absorption. (3) Suitability to any type of special lens (prismatic, lenticular, or bifocal lenses of any type). (4) Special coatings with gradually diminishing thickness (dichromatic coatings) or on certain areas of the lens only, for any lenses whether spherical, toric or other special types. (5) A large choice of different coatings for special purposes. (6) Comparatively low cost.

That sun-glasses with lenses coated by the vacuum evaporation process have stood the test of practical use is shown by the fact that hundreds of thousands of such sun-glasses are worn, not only in temperate regions but in the tropics and in desert countries under adverse climatic conditions and have demonstrated their high resistance to wear, atmospheric conditions and mechanical strains.

TYPES OF DEPOSITED THIN LAYERS

Figure 1 shows two transmission curves of different absorbing power of coatings applied by vacuum evaporation for general use. Curve

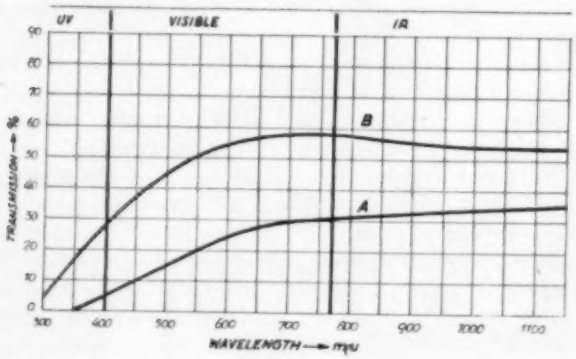

Fig. 1.

A is for a coating absorbing 75% and curve B for a coating absorbing 50%. It can be seen that these coatings not only absorb part of the visible spectrum but also provide protection from harmful ultra-violet radiation and from a high proportion of short wave infra-red radiation.

These coatings are of the multi-layer type with individual layers formed of metallic oxides and possessing a definite absorption with either one or two additional layers for reducing reflections. The coating is applied to the surface of the lens facing the eye of the wearer and shows the well-known purple sheen also seen with other anti-reflection coatings. The color of transmission and reflection seen from the front is greyish-brown and is agreeable to the wearer. This shade ensures normal appearance to all natural colors.*

Figure 2 shows curves for the type of lens specially made by Geraetebau-Anstalt Balzers for mountaineers.† The coating of these lenses is identical in composition to that shown in curve A, Figure 1, but is applied to ophthalmic glass of sage green color. Under the extremely brilliant lighting conditions prevailing on glaciers and extended snowfields, this coating provides anti-glare vision without eye-strain and also protection to the eye from harmful radiation.

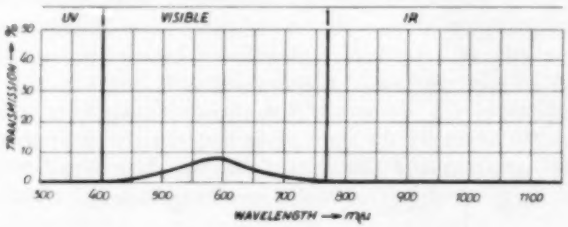

Fig. 2.

Figure 3 represents the characteristics of two kinds of protective lenses having layers, the absorption of which decreases gradually from the upper to the lower edge. Curve A is for a coating applied to sage green glass and curve B for a coating on colorless glass. The deposition of the layers is again similar to those represented in Figure 1. Protective lenses of this type are popular with motorists and aircraft pilots on account of the reduction of the absorption across the lenses.

Figure 4 illustrates a vacuum deposited coating of an entirely different type. Here we have a combination of layers of slightly yellowish-brown color which seem to increase visual contrasts and improve

*Trade names. Vitrosan, Neo-Solex and Perfa-Color. †Valuna.

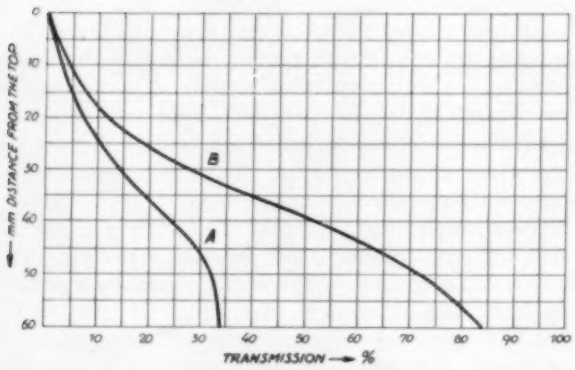

Fig. 3.

the sharpness of vision and the resolving power of the eye by brightening the field of view. This is achieved by selecting layers which completely absorb all radiation up to about 3750 $A\mu$ and for higher wavelengths absorb progressively less. From about 5500 $A\mu$ upwards and into the short-wave infra-red the transmission value fluctuates between 80% and 90% (as shown by the continuous line in Figure 4). This coating consists of a layer of a glass-like substance of low absorption (an oxide of silicon) and of a second layer of low refractive index to reduce reflection. On account of the rapidly diminishing transparency shown in the curve by the steep slope between the short-wave end of the visible spectrom and the ultra-violet, this filter lens,* absorbs the

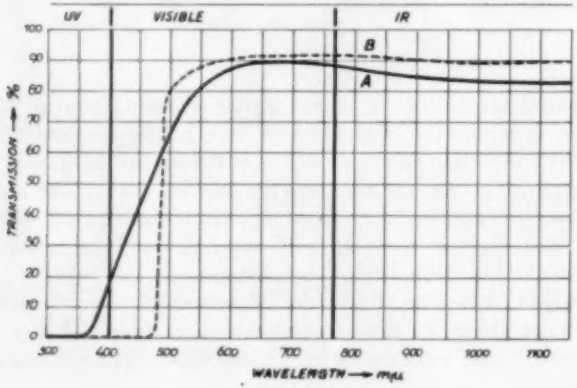

Fig. 4.

*Trade name Samina.

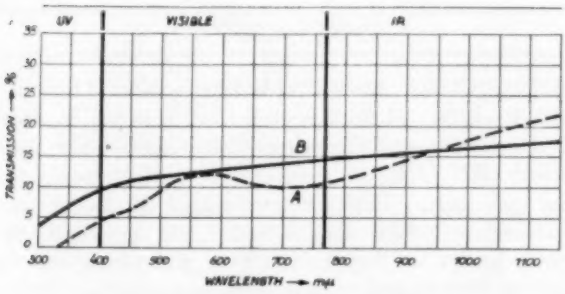

Fig. 5.

scattered blue and violet light heavily, thus seemingly increasing the visibility of distant objects in hazy or foggy weather.

Since this type of coating increases contrast and brightens the field or view it is useful for sportsmen. It does not impair perception and discrimination of colored objects, as does the yellow glass frequently used which has a nearly vertical slope of the transmission curve at about 5000 Aμ (e.g., the Schott filter glass GG 11 shown by the dotted line B in Figure 4), and this seems to result in less eyestrain.

Finally there are the sun-glasses with vacuum deposited reflecting layers. The special color effects are obtained by depositing an additional layer on top of those already mentioned and this layer acts like a mirror. Although such lenses are chiefly worn for unusual fashion effects in color they are nevertheless equal in protective efficiency to conventional sun-glasses. With lenses of this type the absorbing and reflecting layers are applied to the front surface of the lens and they reflect any one of the many colors now popular, including gold, red, green, blue, steel blue and silver. The anti-reflection layer is deposited on the surface of the lens nearest the eye of the wearer.

The dotted curve A in Figure 5 shows the percentage transmission of a coating reflecting red while the continuous line B relates to a reflecting coating of silver color. The color by transmission of the mirror coatings which reflect and absorb about 80% of the light is a greyish-brown with a slight tint of the color complementary to the one reflected by the mirror coating.*

*Trade name, Mirosan.

BOOK NOTICE

DEVELOPMENTAL ABNORMALITIES OF THE EYE. Ida Mann, C.B.E., D.Sc., M.B., B.S., F.R.C.S., F.R.A.C.S. Published by the J. B. Lippincott and Company, Philadelphia. 419 pages. Illustrated. Cloth. $15.

Most optometrists and ophthalmologists in clinical practice meet ocular anormalities which puzzle them. Are they developmental or pathological, benign or malignant? Few individuals except those in the out-patient departments of large teaching hospitals in medical centers have the opportunity to see a sufficiently large number of such cases to be reasonably sure of their ground when one is encountered.

Among such privileged people is the well known British opthalmologist, Ida Mann, late senior surgeon at the Royal London Ophthalmic Hospital and professor of ophthalmology at Oxford. A committee of the BRITISH JOURNAL OF OPHTHALMOLOGY sponsored a 1937 monograph on developmental abnormalities of the eye by Dr. Mann. This work has been revised and is now available in an American edition.

The volume opens with a discussion of normal growth and development as a background for understanding the etiology of abnormal eye conditions, then describes the pathogenesis of the whole range of abnormalities met in eye work. They are grouped according to the affected part such as "Abnormalities of the Fundus Oculi" and "Abnormalities of the Conjunctiva and Sclera," etc.

The book is a particularly practical reference work since it is full of illustrations and cases. Basing her opinions on a thorough grounding in embryology, heredity and genetics the author draws conclusions on the causes of the developmental variations she describes. Dr. Mann's considerable clinical experience also colors her work, keeps it practical and free of the flights of theoretic fancy that is of little interest to the garden variety of practitioner. Another feature that makes this an outstanding book, in the opinion of the reviewer, is the presence of a sixteen page bibliography.

Optometrists, ophthalmologists, child psychologists and psychiatrists, and even general practitioners should add this book to their libraries.

THOMAS H. EAMES, ED. M., M.D.

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OBITUARY

GEORGE A. MacELREE, O.D.

Dr. George A. MacElree, professor of ocular pathology at the Pennsylvania State College of Optometry, passed away on May 8, 1957. He apparently had been in good health and the news of his passing came as a shock to his many friends.

Dr. MacElree was the son of a Philadelphia physician, the late Dr. George A. MacElree, Sr., one who always showed great interest in optometry, and undoubtedly influenced the son's matriculation in a college of optometry. A graduate of the Pennsylvania State College of Optometry in 1924, Dr. MacElree was appointed to the faculty immediately following his graduation and began his teaching duties as an instructor in clinical optometry. Dr. MacElree proved to be such an able teacher that many departments requested his services, with the result that he served at different times in the departments of anatomy, geometrical optics, physiological optics, and optometry. Probably due to his family background, his interest centered on ocular pathology and he progressed in the department of ocular pathology until he became head of the department, a position which he held since 1934. In 1935, Dr. MacElree wrote his popular *Manual of Ocular Pathology for Optometrists*, a textbook which is now in its seventh edition and is widely used throughout the country.

Dr. MacElree was an outstanding lecturer. He devoted his life to the welfare of his college and his profession. He was regarded as the most popular faculty member of P.S.C.O. and served as faculty adviser to many classes. At the time of his passing, Dr. MacElree was adviser to the class of 1957. Dr. MacElree was vice-president and treasurer of P.S.C.O. for a number of years. In 1930, he was active in the college building campaign as secretary of the campaign committee. He was a member of the Academy.

The death of Dr. MacElree has made a profound impact on the students and faculty of P.S.C.O., and is a great loss both to the college and to the profession. He left a substantial bequest to the college. A gentleman and a scholar always, he served as an inspiration to his students and will be long remembered by all who knew him.

ALBERT FITCH, O.D.,
PRESIDENT
PENNSYLVANIA STATE COLLEGE OF OPTOMETRY

CURRENT COMMENTS

Terry Judith Parkins
Editorial Assistant

Optometrists will confer a favor by sending news items of general interest for this department; such as relate to new instruments, clinical techniques, education, visual health and optometric legislation and organization.

ADDITION TO OPTOMETRY BUILDING AT OHIO STATE

Included in the "Additions and Betterments Bill," first passed by the Ohio General Assembly on May 29th and approved June 18th after the consideration of amendments to the Bill, is an item of six hundred thousand dollars for an addition to the Optometry Building at The Ohio State University. This appropriation will provide for an increase in space approximately the size of the present Optometry Building. It will be connected with the existing building facing West Tenth Avenue. When completed it will permit vacating the space in Mendenhall Laboratory which the School of Optometry has continued to occupy since the new building was completed in 1951.

The new addition will contain a class room, seminar rooms, fifteen new refracting rooms, facilities for special clinics in contact lenses, aniseikonia, subnormal vision and orthoptics, a mechanical optics laboratory, an applied pathology clinic, physiology optics laboratories, and office space for instructors. It is estimated that about four hundred and fifty thousand dollars will be used for the building and about one hundred and fifty thousand dollars for equipment and furnishings. The completion of the new addition will increase the value of the Optometry Building, equipment and furnishings to well in excess of one million dollars.

Qualified students from anywhere in the United States or Canada will be considered for admission after completing their pre-optometry requirements either here or in any accredited college or university. Inquiry concerning the entrance requirements, or the procedure in applying for admission should be directed to The Ohio State University, School of Optometry, Columbus 10, Ohio.

ACADEMY BOOTHS AT FAIR AND CONGRESS

The American Academy of Optometry occupied a booth at the Optical Fair, Palmer House, Chicago, June 7-10. The Academy also shared a double-booth with the Los Angeles College of Optometry at the Annual Congress of the American Optometric Association, Statler Hotel, Los Angeles, June 23-26. In each instance the space and cost of the booth was contributed to the Academy: at the Fair, by the

Optical Manufacturer's Association, and at the Congress, by the American Optometric Association.

In Chicago, the booth was planned and staffed by the Illinois Chapter of the Academy with Dr. Alfred Rosenbloom and Dr. Grace Stevesson in charge. In Los Angeles, the Southern California Chapter with the cooperation of the Los Angeles College of Optometry set up the exhibit and staffed the booth during the meeting. Dr. Arthur E. Hoare, Glendale, California, and Dr. Harry A. Jankiewicz, Los Angeles, were in charge of the booth. Academy president Tubesing and secretary Koch spent some time at each booth welcoming members and discussing the educational phases of the Academy with prospective members.

This is the first time the Academy has had the opportunity to present its program in this manner, and the officers and executive council are appreciative of the assistance given the Academy by the O.M.A. and the A.O.A. We hope we will again be invited to participate in future events of this type.

NEWS BRIEFS

The board of directors of the Shuron Optical Company, Geneva, New York, have re-elected Mr. Donald F. Southgate, president and Dr. Roy Marks, executive vice-president, at their June meeting. The company has also announced that it has ceased manufacturing all 6-base single vision lenses and will make only Widesite corrected curve lenses in the future. . . . The Bureau of Visual Science, American Optical Company, Southbridge, Massachusetts, announces a post-graduate course on aniseikonia, October 7-9. This course is open to optometrists and ophthalmologists. A course on refraction for optometrists will be held October 28-30. Early registration is advisable. Dr. Paul Boeder, director of the Bureau of Visual Science has been re-elected president of the Retina Foundation of Boston. . . . Mr. E. Hudson Titmus, president of the Titmus Optical Company, Petersburg, Virginia, announces the appointment of Dr. R. A. Sherman to the staff of the new Department of Occupational Vision. Mr. Titmus also announces a substantial grant-in-aid for the development of the Carl F. Shepard Memorial Library at the Illinois College of Optometry. . . . Bausch & Lomb Optical Company, Rochester, New York, announce the publication of a new book, *The Story of Wilbur T. Mize*, this being a whimsical reminder to patients of the advantages of more than one pair of spectacles. This 48 page cartoon volume is nicely bound and is designed for optometrists' reception rooms. The cost is $2.50. The book will provide a smile and at the same time drive home the multiple pair

concept at the very point of contact. . . . 1,549 optometrists were registered at the Optical Fair, Palmer House, Chicago, June 7-10. The Optical Manufacturers Association has announced that the 1958 Fair will be held at the New York City Coliseum, November 14-17. . . . Dr. T. A. Brombach, San Francisco, has been elected to head the Distinguished Service Foundation of Optometry, succeeding the late Dr. Laurence P. Folson. . . . The large Dr. Bernard Sachs Memorial collection of technical books was presented to the Pennsylvania State College of Optometry by the Gryphons Club of Philadelphia on April 24. . . . The A.O.A. will be represented by a booth at the National Safety Congress, Conrad Hilton Hotel, Chicago, October 21-24. . . . Dr. Otto R. Engelmann, Chicago, was one of the speakers at the International Optical Congress, Amsterdam, Holland, June 10-15. . . . Dr. Wallace R. Brode, associate director for chemistry of the National Bureau of Standards, has been chosen as the president-elect of the American Association for the Advancement of Science. . . . The Optometric Center of New York presented a symposium on glaucoma on May 19. The speakers were Dr. Arthur Schlaifer, associate professor of pathology, Pennsylvania State College of Optometry, who spoke on "Signs and Symptoms of Glaucoma;" Dr. Harold Simmerman, associate professor of pathology, Pennsylvania State College of Optometry, who spoke on "Visual Fields in Glaucoma," and Dr. Paul Shulman, director of research, Illinois College of Optometry, who spoke on the "Wolfe-Scleral Tonometer." Dr. Alden N. Haffner, New York City, was in charge of the meeting.

ABRAM RESIGNS FROM ILLINOIS COLLEGE STAFF

Dr. Morton L. Abram, vice-president of business administration, Illinois College of Optometry, Chicago, has resigned his staff position, effective at once. His office has been discontinued, and his duties have been consolidated with those of the office of president. The presidency will now be a full time staff position. Dr. Eugene Strawn, Freeport, Illinois, will continue as president of the college in the newly expanded office. The Board of Trustees accepted Dr. Abram's resignation with regret and voted him a very substantial monetary award for his 13 years of service to Chicago College of Optometry and to Illinois College of Optometry.

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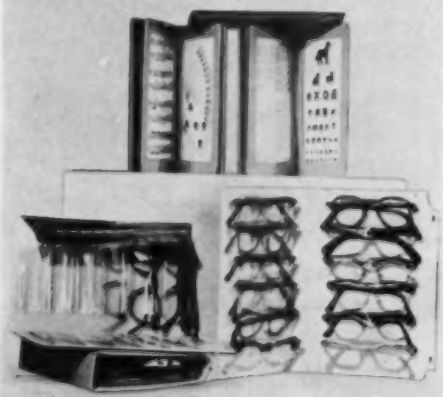

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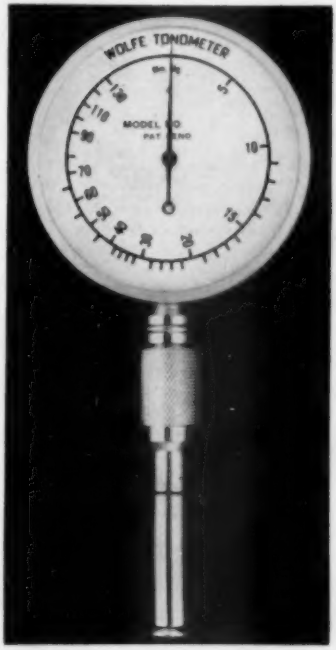

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THE CORRECTION LENS

This report deals with the eye as an optical system and the lenses which are used in correcting the deficiencies of this system. The author reviews the mathematical discipline on which lens corrections rest and combines this with the ametropias corrected by these means. Written by Dr. Julius Neumueller, Pennsylvania State College of Optometry. Write for Monograph No. 52. 60 pages and cover. 90 cents. Send stamps or coins to

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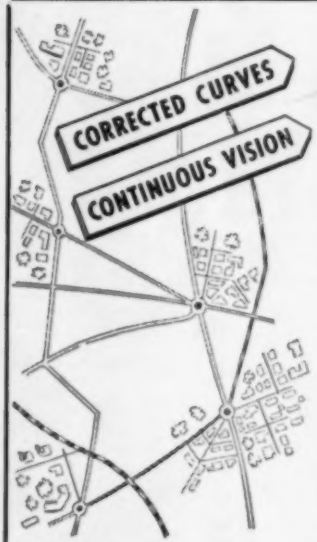

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